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Using Variable Speed Drives, Servo Motors and RS-485 Communication in a Solar Tracking System for Educational Purposes

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"A report submitted to the School of Engineering and Energy, Murdoch University in partial fulfilment of the requirements for the degree of Bachelor of Engineering"

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Abstract

This thesis covers the development of the solar tracking system that is to be installed at the Murdoch University South Street campus. Work had previously been completed on this project by students of ENG454 in 2009 and by Rhyss Edwards as part of his thesis "Control System Design and Commissioning of Photovoltaic Trough Concentrator Systems Installed at the Murdoch University South Street Campus" in 2010. The major focus of this thesis was to cover the communication and data transmission between the variable speed drives, servo motors and the Labview controller over a RS-485 network. The final system is to be used as a learning tool for engineering students.

During this thesis a large emphasis was placed on the research and documentation of the existing tracking system. Information regarding the variable speed drives, servo motors and RS-485 communication was gathered in order to gain an understanding of how the system interacted. From here documents were produced regarding the installation of SEW VSD's and controlling the solar tracking program in order to aid future students who may work on this project.

Robust testing of the existing system was undertaken in order to discover any deficiencies that may be present. Re-wiring of the bench-top system took place to establish communication between the variable speed drives and the Labview Controller. Modifications were made to the existing Labview controller. This focussed on the structure and sequencing of a data transmission process, from the controller to the VSD, across an RS-485 network. Changes were made to the front panel of the controller to enhance operator usability.

At the completion of this thesis it was discovered that the solar tracking system has a large scope for future work to be completed on it. Further advancements to the Labview controller will need to be made before the project is able to be commissioned.

Acknowledgements

For their assistance and guidance throughout this project I would like to acknowledge the following individuals:

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CHAPTER 1: Introduction

1.1 Project Overview

When the engineering department at Murdoch University relocated to the Murdoch Campus, the existing 80 panelled photovoltaic trough solar tracking array at the Rockingham campus was also relocated. A decision was made to construct a 40 panelled array utilising the old system and for two smaller solar tracking systems to be designed and constructed at the Murdoch Campus. Instead of purchasing an off the shelf controller which are readily available, it was decided that the two smaller systems were to be designed utilising variable speed drives, servo motors and RS-485 communication. Variable speed drives are readily found in many motor driven systems and in industrial applications. They offer increased motor control and improved energy efficiency. The use of these technologies would provide a final system that could be readily used for educational purposes. The project was commenced by ENG454 students in 2009 and was taken over as part of Rhyss Edwards's thesis in 2010 [1].

This project was taken over at a stage where the tracking program was functional but contained issues and problems that needed to be addressed. A lack of documentation regarding connections and wiring, drive initialisation and the Labview controller was noticed from the beginning and this caused issues in getting the system back to a functional stage. Considerable importance was placed on research into the existing set up, with the aim of developing relevant documentation for the installation and operation of the solar tracking system.

The developed system will provide a working controller that can successfully transmit data to the variable speed drives whilst providing the user a graphical interface from which they can monitor and control the system. The program and documentation produced will enable students and teaching staff to utilise the main components in projects other than a solar tracking system. These can include motor driven applications where a VSD is used to control the motors.

1.2 Project Objectives

The major objective of this project is to further enhance the knowledge of variable speed drives and their associated technologies as used in industrial applications. The complexity of the solar tracking system being developed is relatively high and the knowledge and understanding that will be gained will aid staff and students in the future use these technologies. The project was split into three key stages; Research and Documentation, Robust Testing and Tracking Program Development. Throughout these stages various objectives were to be achieved. The major objectives for the project were as follows:

- To investigate and research the major hardware components, existing system and produce or acquire adequate documentation.
- To perform robust testing of the existing solar tracking system using the bench top testing platform.
- To further develop the tracking program and fix issues that may have been discovered in the testing stage.

1.2.1 Research and Documentation

At the beginning of this project it was noticed that insufficient documentation was provided by the previous students who had worked on the project. Even though there was a functioning tracking program available this had become non-operational as operating instructions and wiring information were not available. A major emphasis was put into researching the SEW Movidrive VSD's, the communication methods and IPOS control. This research provided an understanding of the existing system from which documentation was able to be produced for future users. Information and documentation is provided on these in further chapters.

1.2.2 Robust Testing of Existing System

The result of Rhyss Edwards's previous work on the solar tracker was a working program available for use. It was first important to establish communication between the VSD's the motor and the master computer. From here the objective was to recreate the system to the point at which it was last operating. The aim was to effectively test the program and the existing system to identify any problems and issues and further develop necessary documentation.

1.2.3 Further Development of Tracking Program

Once issues and problems had been identified in the solar tracking program it was necessary to determine how and what relevant changes would need to be made to the program. This would focus heavily on the communication and transmission of data between the variable speed drives and the master computer on the RS-485 network. Front panel usability would also be addressed so that future students would be able to operate the tracker without problems and more easily.

1.3 Thesis Structure

This thesis is broken down into 7 chapters which provide information on the system and the work completed on the project. The structure of the thesis is as follows:

- **CHAPTER 1:** An introduction to the project and the key objectives.
- **CHAPTER 2:** Provides an overview into the background and theory behind the major components of the solar tracking system.
- **CHAPTER 3:** Covers the solar tracking system, the specific hardware components and the technologies used in the system.
- **CHAPTER 4:** Describes the communication method for transmission of data in a Movidrive variable speed drive.
- **CHAPTER 5:** Explains in detail the connections and communication between the existing bench top testing platform
- **CHAPTER 6:** Outlines the development and changes made to the Labview controller and how it functions.
- **CHAPTER 7:** Covers the achievements made throughout the project and details the future work and recommendations moving forward.

CHAPTER 2: System Background

This chapter will provide a literature review of the hardware and communication standards used in the development of the solar tracking system.

2.1. Variable Speed Drives

This section will provide an overview on variable speed drives, how they function, types of VSD's and the main advantages and disadvantages of using them.

2.1.1. Variable Speed Drive Overview

A variable speed drive (VSD), also known as a variable frequency drive (VFD) or adjustable speed drive (ASD) is a device that, put simply, controls the speed of machinery. To be more precise VSD's allow us to regulate the speed or rotational force of an electric motor [2]. The speed of a motor is determined by the frequency and voltage of the supplied power. It is however, not always ideal for motors to have a fixed speed and thus variable speed drives allow us to control the speed as needed. This is done by altering the frequency of the supply voltage to the motor.

Many systems that are run by motors are often designed so that they are capable of handling peak loads. These systems however are not always operating at these peak loads and as such can become quite energy inefficient when meeting significantly lower loads. Through the use of VSD's we are able to more closely match the output of the motor to the operating load to result in energy savings. [3]

2.1.2 Principles of Operation

As has already been stated, VSD's control the speed of motors by regulating the supply voltage and frequency. There are three main stages to a VSD. They are:

- Rectifier Stage
- DC Filter Stage
- Inverter Stage

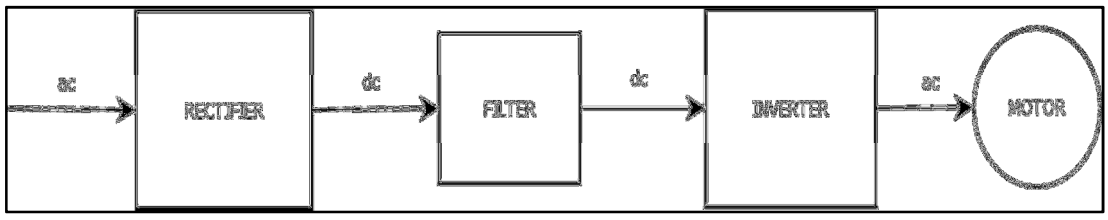

Figure 1 - Block Diagram of a VSD

Rectifier Stage

A power source provides 50Hz 3-phase AC power to the rectifier in the VSD. The rectifier then converts the AC to a DC voltage. This rectifier is made up of 6 diodes known as a diode bridge.

DC Filter Stage

The DC voltage is then passed through a DC filter via a DC bus. The filter helps to smooth out and filter the AC component of the DC waveform [4].

Inverter Stage

The inverter circuit inverts the DC voltage back to an AC Voltage. Depending on the type of VSD this inverter stage can vary. The types of inverter will be covered in the following section. It is what happens in this stage that enables the speed of the motor to be controlled.

2.1.3 Types of Variable Speed Drives

There are 4 main types of variable speed drives. They all operate on the same principle; they all control the speed of a motor by controlling the supply power and frequency. The four main types of VSD's are Pulse Width Modulation (PWM), Voltage Source Inverters (VSI), Current Source Inverters (CSI) and the relatively new Flux Vector Drive. Each type offers certain advantages and disadvantages depending on the motor application.

Pulse Width Modulation

This is the most common technology used in VSD'S. This is largely due to the fact that it works well with motors between 0.5 hp and 500 hp in size [5]. An AC supply voltage is fed into the input side of the VSD which is then rectified through a diode bridge converter to a DC voltage. The DC voltage is then passed through a filter to create and maintain a fixed DC bus voltage [5]. This DC voltage is then fed into an inverter made up of six high-speed electronic switches, usually power transistors or thyristors. The switches create short pulses of differing widths and the same height as the DC bus voltage. This process describes the term pulse width modulation. When the width of the produced pulses is varied in each half cycle, the average output voltage produces a sine wave like output. The frequency delivered to the motor, which in turn controls the speed, is determined by the number of transitions from positive to negative per second of the pulse width modulated voltage. The use of insulated gate bipolar transistors (IGBT) as the switching device is common in many

PWM variable speed drives. They can operate with switching speeds between 2 kHz to 15 kHz [5]. The higher the frequency the less motor whine is present. This is due to the fact that transistors operate outside the threshold of what humans are capable of hearing. It also smooths out the output current waveform because current spikes are now removed. The following table outlines the advantages and disadvantages of pulse width modulated variable speed drives.

Advantages	Disadvantages
Excellent input power factor due to fixed DC bus voltage.	Motor heating and insulation breakdown in some applications due to high frequency switching of transistors.
No motor cogging normally found with six-step inverters.	Non-regenerative operation.
Highest efficiencies: 92% to 96%.	Line-side power harmonics (depending on the application and size of the drive).
Compatibility with multi-motor applications.	
Ability to ride through a 3 to 5 Hz power loss.	
Lower initial cost.	
Reflects least amount of harmonics to the power source.	

Table 1 - Advantages and Disadvantages of PWM VSD's [5]

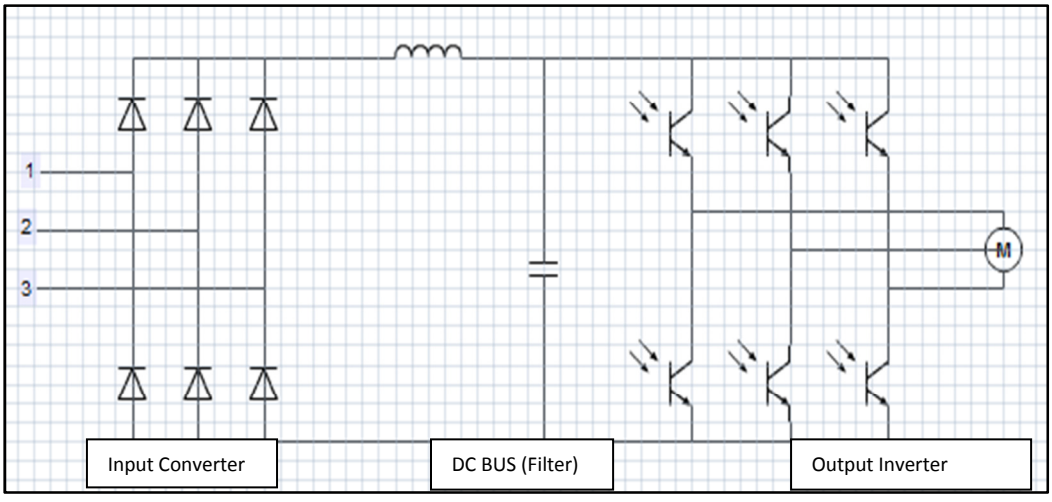

Figure 2 - Basic Topology of a PWM Variable Speed Drive

Current Source Inverters

As the name suggests the DC input to the inverter in current source inverters is seen as a dc current source. They are quite reliable because of their ability to limit the current and their simple circuitry. Current source inverter based VSD's take an AC input voltage and rectify the voltage to DC just as the other types of VSD's do. However, the type of rectifier used differs. Current source inverters use either silicon controlled rectifiers (SCR's), gate commutated thyristors (GCT's) or symmetrical gate commutated thyristors (SGCT's) to convert an AC voltage into DC [6]. A current source inverter regulates the power and produces a variable voltage. The DC bus contains a large inductor which regulates current ripple and also stores energy for the motor. SCR's, GCT's or SGCT's are also used in the inverter stage. The inverter then converts the DC current to AC at a variable frequency. The CSI keeps a fixed current regardless of any voltage changes. The advantages and disadvantages of current source inverter VSD's can be seen in table 2 below.

Advantages	Disadvantages
Reliability due to inherent current limiting operation.	Large power harmonic generation back into power source.
Regenerative power capability.	Cogging below 6 Hz due to square wave output.
Simple circuitry.	Use of large and costly inductor.
	HV spikes to motor windings.
	Load dependent; poor for multimotor applications.
	Poor input power factor due to SCR converter section.

Table 2 - Advantages and Disadvantages of a CSI VSD [5]

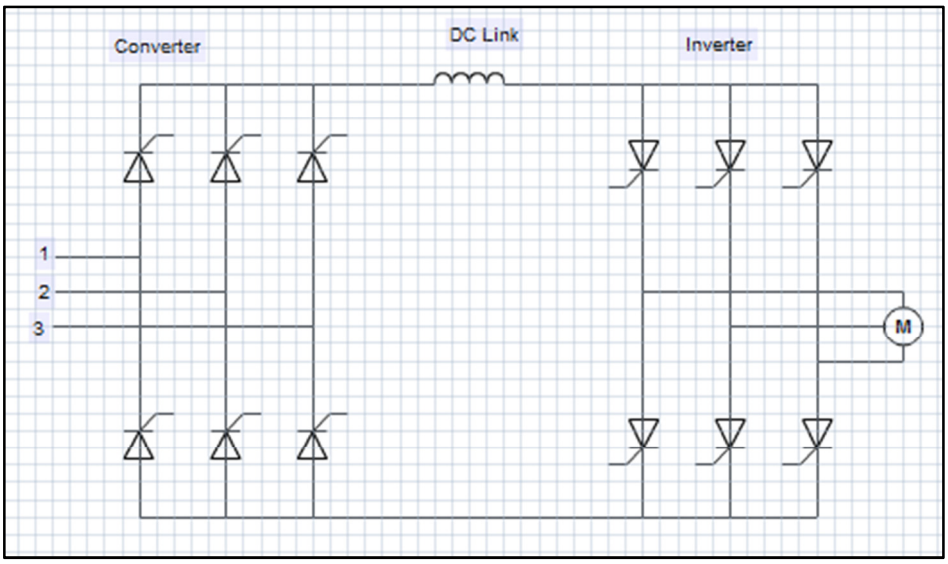

Figure 3 - Basic Topology of a CSI VSD

Voltage Source Inverters

Voltage source inverter VSD's control the motor speed by regulating the output voltage and frequency. The DC input to the inverter is a DC voltage source. Figure 4 shows the basic circuit diagram of a voltage source inverter VSD. VSI's use either SCR's, GCT's or SGCT's much the same as CSI's do to rectify the input ac voltage [5]. The voltage is then input to the DC bus, in this case a filter, to be smoothed out and is then the input to the inverter. The voltage is always fixed regardless of the current. The VSI uses transistors, SCR's or gate turn off thyristors (GTO's) in its inverter to produce a six-step output waveform [5]. Unlike the CSI the VSI is not a current regulator but rather a voltage regulator. Voltage source inverter VSD's have advantages and disadvantages and these can be seen in table 3.

Advantages	Disadvantages
Basic simplicity in design.	Large power harmonic generation back into the power source.
Applicable to multi-motor operations.	Poor input power factor due to SCR converter section.
Operation not load dependent.	Cogging below 6 Hz due to square wave output.
	Non-regenerative operation.

Table 3 - Advantages and Disadvantages of VSI VDS's [5]

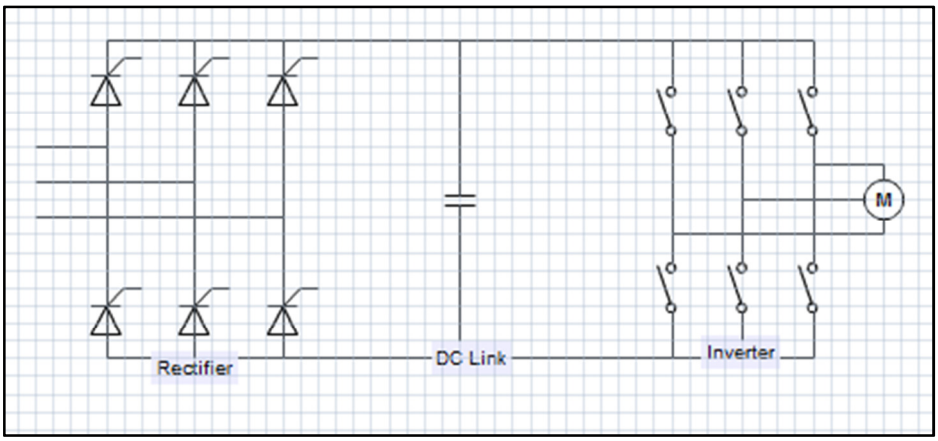

Figure 4 - Basic Topology of a VSI VSD

Flux Vector Drive

The flux vector drive is a relatively new type of pulse width modulation variable speed drive. It addresses the main disadvantage of AC variable speed drives, that they aren't capable of low rpm, high torque application. This had traditionally been the area for DC drives. With the introduction of flux vector drives this philosophy has now changed.

Flux vector drives use a closed loop control that feeds from the motor to the VSD's microprocessor [7]. This enables real time data such as rotor position, speed and load levels to be utilised in the control of the motor speed, power and torque. When the inverter is operated in response to real time conditions it produces pulses that are outside the normal sinusoidal range of controlling motor speed. This enables larger torque levels to be achieved. Flux vector drives are almost exclusively used in applications that require motors to change speed quickly. Using flux vector drives for other applications would be costly and an overkill since conventional PWM variable speed drives are more than capable at handling these situations [5]. The following table outlines the advantages and disadvantages that flux vector drives have in comparison to other variable speed drives.

Advantages	Disadvantages
Excellent control of motor speed, torque, and power.	Higher initial cost as compared to standard PWM drives.
Quick response to changes in load, speed, and torque commands	Requires special motor in most cases.
Ability to provide 100% rated torque at zero speed.	Drive setup parameters are complex.
Lower maintenance cost as compared to DC motors and drives.	

Table 4 - Advantages and Disadvantages of Flux Vector Drives

2.1.4 Advantages of Variable Speed Drives

There are numerous advantages to using variable speed drives in motor applications. These range from greater energy efficiency to reduced system maintenance. The main advantages of using VSD's will be explored in the following:

Energy Savings

The reduction in energy consumption is perhaps the variable speed drive's greatest advantage and one of the reasons they have become so popular in modern systems. AC motors are generally designed to operate at fixed speeds and be able of handling peak loads. This can be quite energy inefficient as the motor will operate at the fixed speed even when the loads are dramatically reduced. Since variable speed drives are able to control the power supplied to the motor they can reduce the speed and thus power, which in turn makes them much more energy efficient. In the case of variable torque loads, a much lower torque is needed at lower speeds as opposed to higher speeds [8]. When the speed is reduced to 50%, the required torque is also reduced to 25%, which in turn reduces the horsepower to 12.5% of the value at full load [8]. This relationship can be seen in Figure 5. For applications with constant torque loads the required torque is the same at high speeds and low speeds. A drop in speed by 50% will result in a drop of power by 50% (Fig 6).

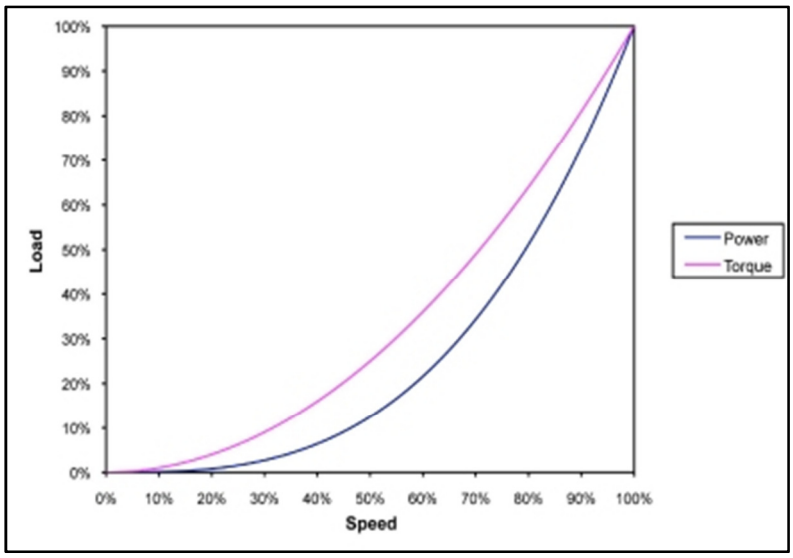

Figure 5 - Variable Torque Load

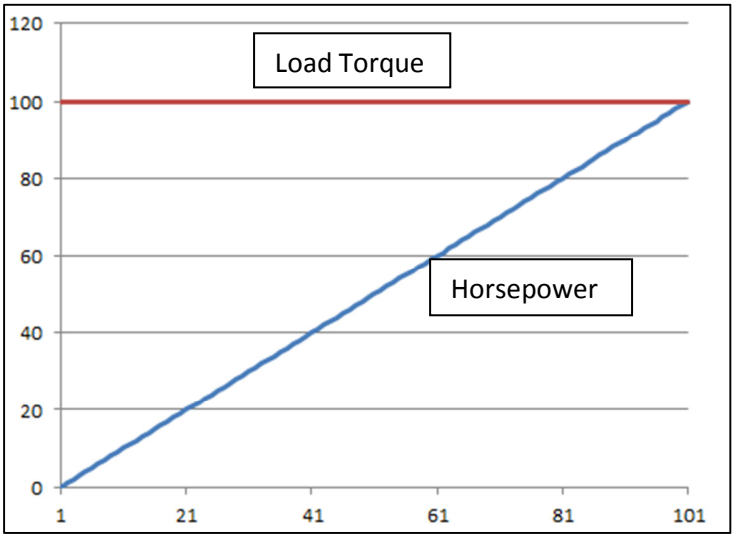

Figure 6 - Constant Torque Load

Reduced System Maintenance

Since non VSD controlled motors are operating to handle peak loads, much more stress is being put on the motor. The ability of the VSD to lower the speed of the motor inherently lowers the stress.

Improved Process Control

Many variable speed drives are able to be integrated into automated process control systems. This allows for process signals to be fed to the VSD for speed control and the

starting and stopping of the drive [8]. It makes the process control system much more dynamic by allowing increased functionality with programmable logic controllers and distributed control systems.

Lower Start-up Voltage

When the motor is started the amount of in-rush current is limited by a variable speed drive because the motor can gradually build up speed [8].

Multi-motor Capability

Depending on the type, variable speed drives can be capable of controlling multiple motors from the one device. This decreases the initial cost of implementing VSD's as only one drive is required for multiple motors.

2.1.5 Disadvantages of Variable Speed Drives

Whilst there are many advantages and benefits of using variable speed drives in motor driven systems there are also some disadvantages as follows:

Initial Cost

Compared to other speed control methods for motors, variable speed drives have a higher initial cost. It has been stated that VSD's offer energy savings, and this can offset this initial cost. However for motor applications that require the motor to operate, on average, close to the rated speed level, the energy saving is minimal and may not justify that cost [8].

Heating of Motor at Low Speeds

When operating the motors for constant torque applications at low speeds, motor heating can become an issue. This is due to a number of factors; the first being that at low speeds a motor cooling fan produces less air. The current to the motor also remains constant regardless of the speed. The combination of these factors results in a greater risk of overheating since there is less cooling air but the current remains the same.

Maintenance

Being electronic devices, VSD's requires additional knowledge of the device to be able to troubleshoot or fix problems that arise. This may mean that a contractor will have to be brought in who is specific to that product to be able to fix it.

Harmonics from Output

Since the electrical waveform generated by the VSD is not a pure sine wave, harmonics are seen in the waveform and are supplied to the motor. These harmonics contain a current component and with that create heat in the motor. Due to these harmonics VSD's create between 5 - 8% extra heat as opposed to a motor without a VSD [8].

Induced Power Line Harmonics

VSD's can induce waveform distortion, in the form of harmonics, on the input power supply. The way in which current is pulled off the waveform, in non-sinusoidal pulses, means that harmonics and line distortion become an issue [8]. This can impact the rest of the power supply in the facility and will require adequate protection on other devices.

2.2. RS-485 Communication Overview

This section provides a technical overview as well as background information on the serial communication standard RS-485.

2.2.1. Serial Communication

Serial communication is the process of sending and receiving a byte of data (8 bits), one data bit at a time. This differs from parallel communication which sends a byte of data down 8 parallel channels. The advantages of serial communication are:

- Simplicity – Serial communication needs less wires and also takes up less space.
- Ability to be used over longer distances – Serial communication can be transmitted over lengths up to 1200m.
- Less Interference –Specifically crosstalk.

Serial data transfer can be done in two ways; Synchronous transmission and Asynchronous transmission. These methods will be discussed, below.

Synchronous Transmission

Synchronous transmission of data relies on a clock signal to synchronise the sender and receiver. That is, there is an agreed upon time at which data is transferred. Data is continually sent between the sender and receiver at the agreed upon intervals. Regardless of whether or not there is data to be transmitted, a fill character is sent to ensure that data is continually transmitting [9]. It can be more effective because only the data bits are being sent and no start, stop or parity bits. Problems can occur when the clocks of the sender and receiver get out of sync. This can potentially result in the transmission of corrupt data.

Asynchronous Transmission

Asynchronous data transmission relies on extra bits, added to the data to signify the starting and stopping points of the data transmission. This can be seen in Figure 7. A start bit is added to the start of the data byte and a stop bit at the end. A parity bit may be added before the stop bit for error checking purposes. The start bit signifies to the receiver that data is ready to be transmitted and the stop bit confirms that the data has been sent. If the stop bit doesn't appear as it should then the receiver recognises an error and assumes the data to be corrupt.

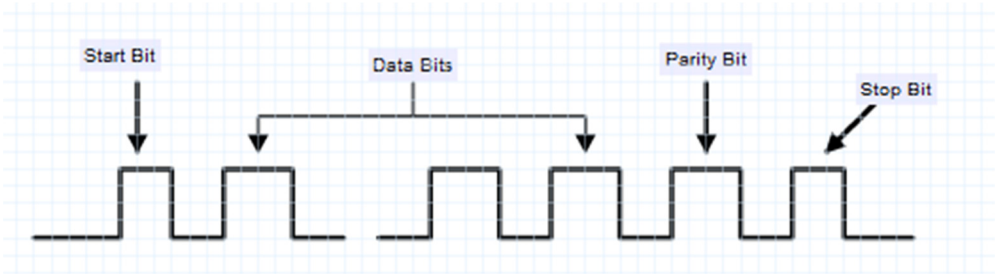

Figure 7 - Asynchronous Serial Data Transmission

2.2.2. RS-485 Standard

RS-485 is a serial communication standard that is based on the RS-232 standard. The official title for the RS-485 standard is Electrical Characteristics of Balanced Voltage Digital Interface Circuits; this is published by the ANSI Telecommunication Industry Association/Electronic Industries Association (TIA/EIA) [10]. RS-485 is a popular communication method in industrial process due to the fact that it can be used over long distances and it can support multiple devices on the one bus. The RS-485 standard only addresses the lowest level of the open system interconnection (OSI) model, the physical layer.

Data Transmission

Data in a RS-485 network is transmitted differentially on a two-wired twisted pair bus. That is, the transmitter and receiver are connected to two wires that have been twisted together. The twisting is desirable, as it cancel out electromagnetic interference from external sources. With a two wired RS-485 system the difference between the voltages of the wires is what transmits the data. Logic 1 is defined by one polarity of the voltages and the reverse polarity defines logic 0 [9]. It requires a minimum of a 0.2V differential to operate and the applied voltage can be between -7V and 12V. Whilst RS-485 is known as a two wired network it is also possible to have a four wired network. Two wired networks only operate in half duplex mode. For this reason, the send and receive signals are sent on the same wire and thus, only one device can transmit at any given time. With a four wired network there are two sets of twisted pair wires allowing for both pairs to be able to transmit and receive simultaneously. This is known as full duplex communication.

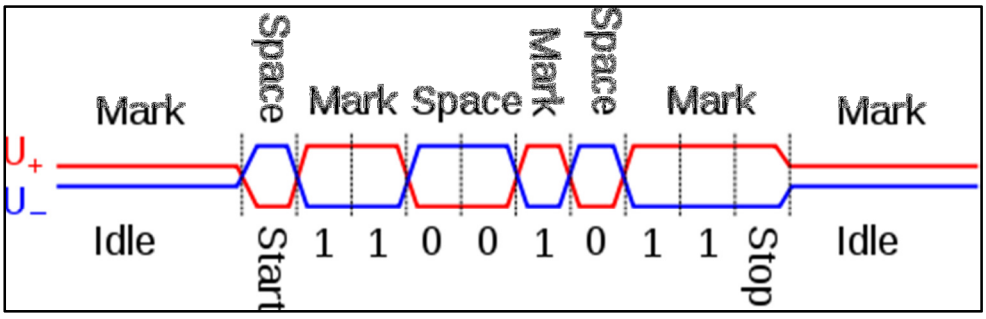

Figure 8 - RS-485 Data Transmission Waveform [11]

Network Topology

The recommended network topology for RS-485 networks is point to point series connection nodes, a bus, or a line network topology [9]. Star and ring topologies are

generally not recommended due to signal reflections and termination impedance issues. Termination resistors between the ends of the wires are generally needed to protect from reflection from the drivers. Without termination, the resulting reflection can cause the data to be corrupt.

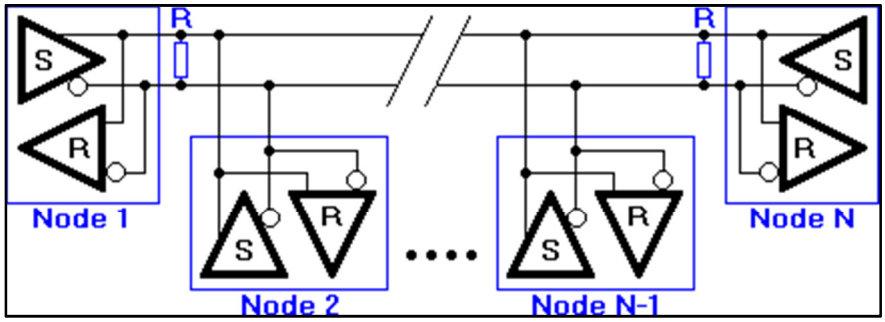

Figure 9 - Recommended RS-485 Network Topology [12]

2.3. Synchronous and Servo Motors

The solar tracking system uses synchronous servo motors to drive the tilt and roll mechanisms. This section will discuss the principles behind servo and synchronous motors.

2.3.1. Synchronous Motors

A synchronous motor is a motor that operates in synchronism with the frequency of an AC supply current. The speed at which the shaft rotates is synchronised to this frequency [13]. This type of motor is generally used where an accurate and constant speed is needed. It doesn't require slip for torque to be produced and therefore can produce torque at synchronous speeds.

2.3.2. Principles of Operation

A three phase voltage is applied to the stator windings which in turn induces a rotating magnetic field. This magnetic field's rotation is synchronised with the frequency of the supply current. The rotor winding, which has its own magnetic field, tries to lock in to the rotating magnetic field of the stator by creating a torque that rotates the rotor. If this occurs the motor is said to be in synchronisation [13].

The synchronous speed of a synchronous motor can be determined by the following formula:

$$n_s = \frac{120 * f}{p}$$

Where n_s is equal to the synchronous speed, f is equal to the frequency of the supply current and p is the number of poles in the synchronous motor.

2.3.3. Types of Synchronous Motors

There are two types of synchronous motors: non excited motors and DC excited motors. These two types of synchronous motor are differentiated based on the methods of providing the rotor magnetic field.

Non Excited Motors

This type of synchronous motor has a rotor that is made of solid steel. The magnetic field of the stator rotates and, as a result the magnetic field of the rotor (and thus the rotor) must constantly try to catch up to the stator by rotating synchronously with it [13]. An induced magnetic field on the poles of the rotor is created by the stator field. There are three types of non-excited motors:

- Permanent Magnet Motors
- Hysteresis Motors
- Reluctance Motors

DC excited Motors

These motors are excited by a direct current. The direct current is supplied to slip rings to excite the motor. Current is conducted to the rotor through slip rings and brushes [13].

2.3.2 Servo Motors

A servo motor is a type of motor that uses a control loop and provides feedback to determine the motors position [14]. The feedback information, often provided by some form of encoder, is used to control a motors speed and position. As a control loop is required a type of control is needed. Servo motors often utilise a proportional integral derivative (PID) control method. The advantages of a servo motor are:

- High intermittent torque
- High torque to inertia ratio
- High speeds
- Work well for velocity control
- Available in all sizes
- Quiet [14]

The disadvantages of servo motors are as follows:

- More expensive than stepper motors
- Cannot work open loop since feedback is required
- Require tuning of control loop parameters [14]

Servos are often used in conjunction with variable speed drives. They are a popular choice for industrial applications due to their accuracy and reliability.

CHAPTER 3: System Overview

An existing bench top testing system was set up in the mechatronics room. This contained two SEW Movidrive MDX61B variable speed drives, two SEW DFS synchronous servo gearmotors and the associated cabling and connections. A designated master computer was also present which contained the relevant software and communication adapters. This section will discuss the hardware that was present on the existing system and the plans for the final system.

3.1. Solar Tracking System

Although the major focus of this project was on the variable speed drives and their communication with a computer based controller, it is important to understand how the final system will be constructed and controlled. The solar tracker consists of a tilt mechanism and a roll mechanism. The tilt mechanism controls the movement of the solar tracker in a north/south orientation whereas the roll mechanism moves the array in an east/west motion in the path of the sun. The mechanisms to control these movements consist of a variable speed drive and a servo motor for each of the tilt and roll mechanism.

3.1.1. Motor Mount

There are various methods of mounting the motors for operation of the solar tracking system. These included a linear actuated drive and a chain drive. However, as was mentioned in Rhyss Edwards's thesis [1], a decision had been made in consultation with engineering staff members to proceed with a direct drive motor mount. This motor mounting method can be seen in Figure 10. In order to employ this method the gear units must be mounted upside down. However, the oil filter, drain plug and breather must be shifted to the base of the gear unit as was discovered by Rhyss Edwards [1]. This mounting position can be seen in Figure 11.

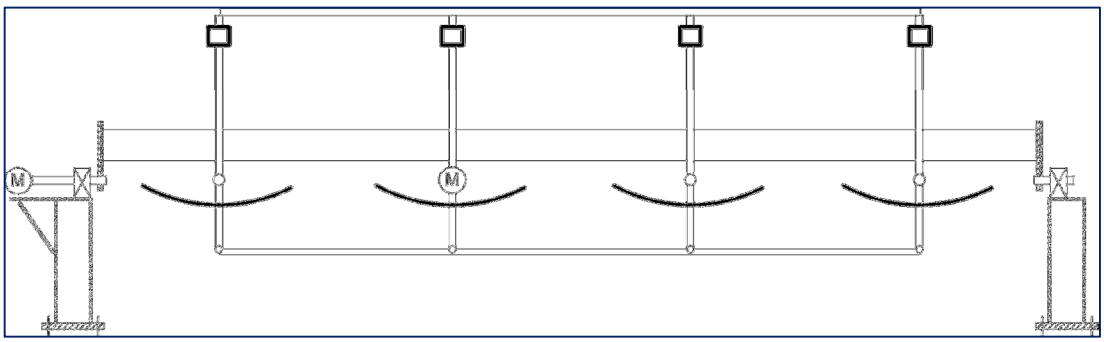

Figure 10 - Direct Drive Motor Mount [1]

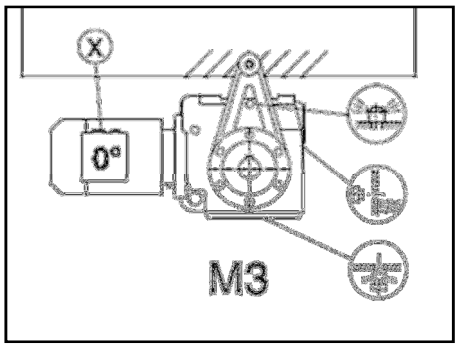

Figure 11 - Upside Down Mounting Diagram [1]

3.1.2. Chronological Tracker

There are a number of controllers which utilise different methods to track the sun. These can include a passive tracker, an active tracker and a chronological tracker. The type of controller used in this solar tracking system is a chronological tracker. Other controller types rely on specific renewable energy mediums in order for the trackers to operate. The benefit of a chronological tracker is that any renewable energy medium can be used. This means that several different types of energy mediums can potentially be used on one array. This can be very beneficial if the solar tracker was to be used for educational purposes such as this one. A chronological tracker tracks the sun from sun rise to sun set. The benefit of this type of controller is that it is highly accurate if set up correctly and does not require any feedback to determine the position of the sun. The disadvantage of a chronological tracker is that it will track the sun even on cloudy and overcast days where little to no sun is available. This results in minimal but some, energy inefficiency.

Method of Operation

The way a chronological tracker works is by using a solar positioning algorithm to calculate azimuth and zenith angles from a physical location [15]. Figure 12 shows the azimuth and zenith angles with respect to the tilt and roll references. The algorithm relies on data relating to specific geographic location, date and time. The algorithm is relatively complex and requires information to be calculated in regards to information about the sun. Some of these values that are calculated include:

- The observer local hour angle, (in degrees)
- The geocentric sun declination, (in degrees)
- The topocentric sun right ascension, (in degrees)
- The true obliquity of the ecliptic, (in degrees)
- The Earth heliocentric longitude, latitude, and radius vector (*L*, *B*, and *R*) [15]

These are some of the values associated with the solar position algorithm, the full algorithm and associated information is contained in Appendix E

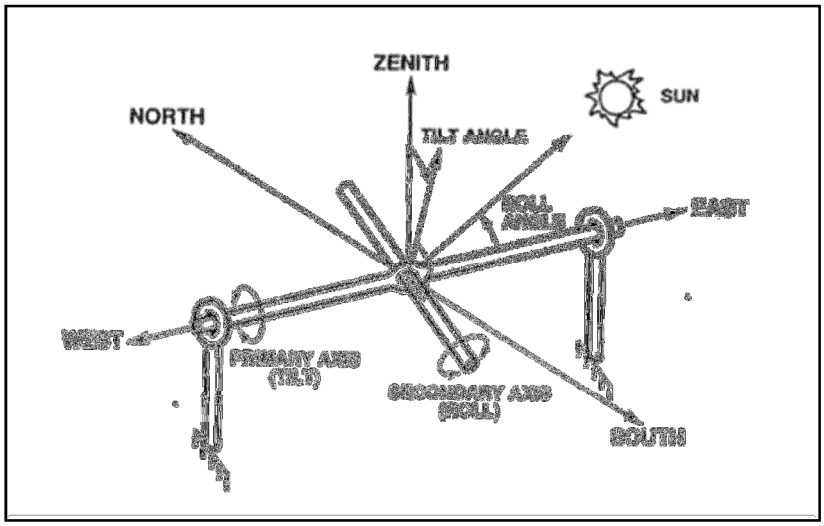

Figure 12 - Zenith and Azimuth Angles Used in a Chronological Solar Tracker [1]

3.2. Movidrive MDX61B

The VSD's that will be mounted to control the tilt and roll motors are Movidrive MDX61B VSD's. The Movidrive MDX61B is a range of drive inverters (VSD) from SEW Eurodrive [16]. The benefits of these drives are that they have a wide voltage range, high overload capacity and extensive functionality and features [17]. The specific versions of both these drives are the standard design drives. The standard version drives come equipped with the IPOS plus integrated positioning and control system. Figure 13 shows a connected MDX61B VSD in full operation

Figure 13 – Connected and Operating MDX61B VSD

Whilst the two drives are the same model, their system capabilities differ. The model numbers for each of the VSD's can be seen in Table 5.

Drive 1	Drive 2
MDX61B-0005-5A3-4-00	MDX61B-0011-5A3-4-00

Table 5 - Drive Model Numbers

The capabilities of each drive, and therefore the differences are as follows, but essentially the differences are output power, output current and the output frequency range.

Drive 1

Drive one has the following input and output data as seen in Tables 6 and 7.

Input	Value
Rated Supply Voltage	3-phase 380V-500V AC
Supply Frequency	50Hz to 60Hz
Rated Supply Current	1.8A AC

Table 6 - Input Data for Drive 1

Output	Value
Apparent Output Power	1.4kVA
Rated Output Current	2A AC
Output Frequency Range	0Hz to 180Hz

Table 7 - Output Data for Drive 1

Drive 2

The relevant drive input and output data can be seen in Tables 8 and 9.

Input	Value
Rated Supply Voltage	3-phase 380V-500V AC
Supply Frequency	50Hz to 60Hz
Rated Supply Current	2.8A AC

Table 8 - Input Data for Drive 2

Output	Value
Apparent Output Power	2.1kVA
Rated Output Current	3.1A AC
Output Frequency Range	0Hz to 600Hz

Table 9 - Output Data for Drive 2

As can be seen drive 2 is a more powerful unit than drive 1. It is capable of driving motors with greater power. The recommended constant load motor power for drive 1 is 0.55kW, whilst the recommended constant load motor power for drive 2 is double that of drive 1 at 1.1kW.

3.2.1 IPOS Plus Positioning and Sequence Control:

Movidrive MDX60B VSD's come equipped with an integrated positioning and control system known as IPOS Plus. The IPOS control enables highly accurate point to point positioning capabilities [18]. The advantage of the IPOS plus system is that it takes most of the real time control away from the master (PLC, PC). That is, the motion control is handled by the variable speed drive itself. The master sends requests to the VSD's on board IPOS program and the IPOS program handles the positioning and sequencing of the motor. This can greatly reduce the load on the master and in some cases it can completely replace it [18].

IPOS programs can be created in the Movitools software package [16] using assembly language. Movitools is SEW Eurodrive's proprietary software that enables the user to set up and program Movidrive VSD's and IPOS programs. Existing application modules are also available to download to the VSD, where the user only has to enter parameters regarding the motor and the VSD's via a setup interface in Movitools.

3.2.2 IPOS Application Modules

There are several application modules available that are essentially pre built IPOS programs for specific applications. They are as follows:

- **Bus Positioning**
  - For applications that require the motor to move to a number of various positions [18]. This is the suitable application module for a solar tracking system.
- **Winding**
  - Winding is used in applications where materials need to be endlessly wound or unwound [18].
- **Flying Saw**
  - This application module is used for materials that require a motor to drive a saw to cut materials at certain lengths [18].
- **Crane Control**
  - This module takes over the entire motion control in applications that require objects to be lifted and transported in various directions [18].
- **Electronic Cam**
  - Used in applications where cyclical machinery is used for complex moving sequences [18].
- **Modulo Positioning**
  - For use in applications that require a rotary movement such as hoists, conveyer belts and rotary tables [18].

Further information can be found in the SEW manual: IPOS Plus Positioning and Sequencing Control in Appendix C

3.3. DFS Synchronous Servo Motors

The solar tracking system utilises two 3 phase SEW DFS synchronous servo motors to position the array, as shown in Figure 14. The benefits of these motors is that they are extremely accurate, have a large torque range and a high overload capability. The motor

has a maximum output torque of 480Nm. The whole motor system consists of three main components, the servo motor, 2 gear units and the encoder.

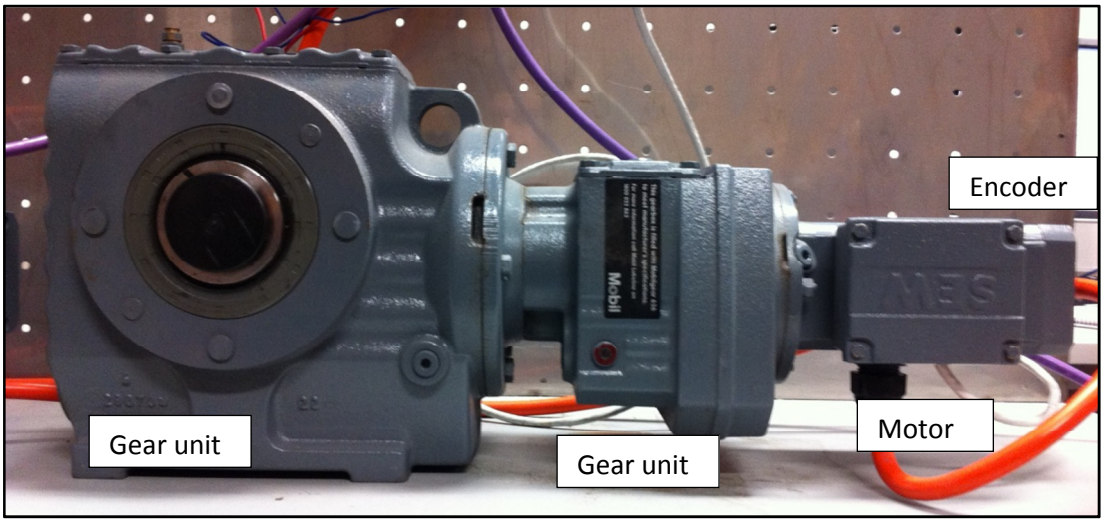

Figure 14 - DFS Synchronous Servo Motor

The technical data for the synchronous servomotors can be found in the following table.

Rated Speed	3000RPM
Standstill Torque	1Nm
Standstill Current	1.65A
Max Motor Current	6.6A

Table 10 - DFS Synchronous Servo Gearmotor Data

Refer to Appendix C for more information regarding the DFS Synchronous Servo Motors.

CHAPTER 4: VSD Communication

A major aspect of this project revolved around understanding and establishing communication between the variable speed drives and the programming software Labview. This project focussed on using an RS-485 interface network to communicate between the drives and the master computer. This section will discuss the method of communication that SEW Movidrives utilise.

4.1. Telegrams

The variable speed drives communicate to the master through use of two types of telegrams. These are the request and response telegrams [19]. The master first sends out a request telegram to the VSD and then receives a response telegram back. As has been discussed earlier RS-485 networks can only be either sending or receiving at any given time so the VSD follows this rule.

4.1.1. Telegram Structure

The structure of each telegram is vital to enable communication with the variable speed drive. The length of each telegram can be anywhere from 6 to 18 bytes (see figure 21 for an example). The telegram starts with an idle time, which is a pause, and is followed by the first byte. This first byte is the start delimiter; this signifies that data is ready to be transferred to or from the VSD. The second byte represents the address of the slave, which is the VSD's address number. The third byte is the Protocol Data Unit (PDU) type and this differentiates whether cyclical or acyclical data transmission is taking place. It also contains information with regards to the length of the telegram. The following 2 to 14 bytes are the Protocol Data Unit (PDU). These bytes are the actual request or response data that is being sent in the telegram. The final byte in the telegram is a block check character (BCC) [19].

Request Telegram Structure

Figure 16 depicts the structure of an RS-485 request telegram being sent from the master to the slave. The start delimiter for a request telegram is the hexadecimal number 02. This signifies that it is a request telegram being sent and differentiates between the two types of telegrams.

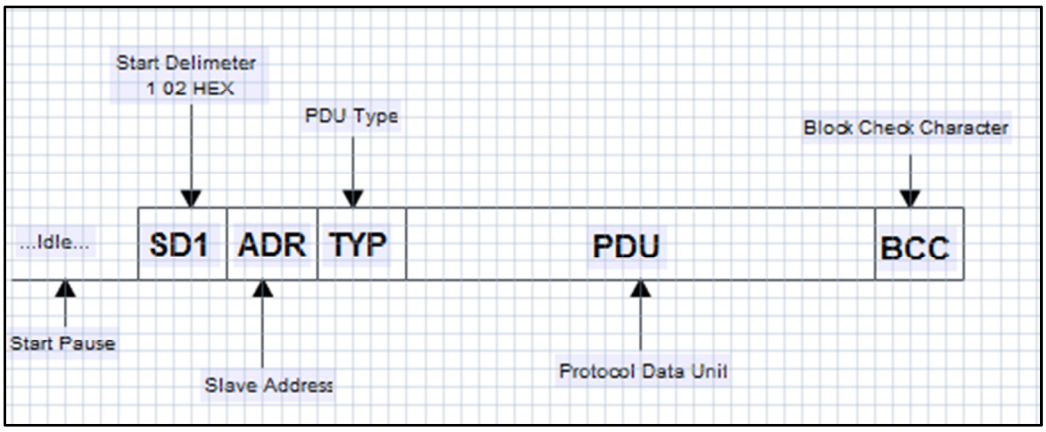

Figure 15 - Request Telegram Structure

Response Telegram Structure

Figure 17 shows the response telegram structure. The structure of the response telegram is identical to that of the request telegram however it is the information in the data bytes that differentiates between the two. SD2, the start delimiter for the response telegram is the hexadecimal number 1D.

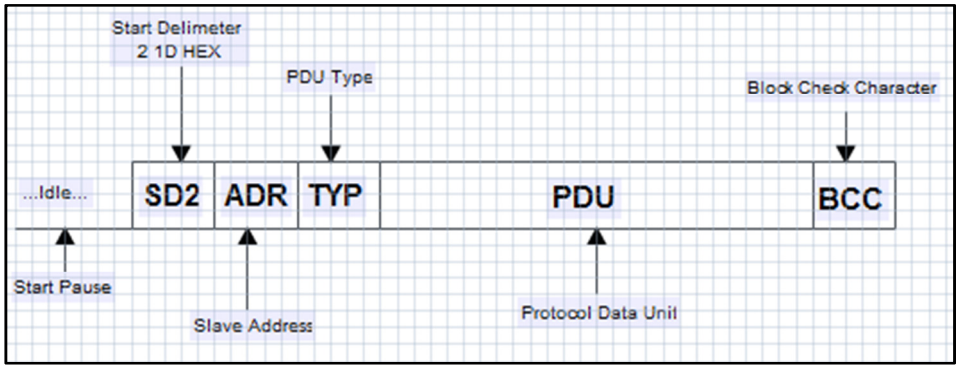

Figure 16 - Response Telegram Structure

Start Pause

The start pause is a pause before each telegram to signify that a telegram has either been sent or is about to be received. It is important for the successful transmission of telegrams between the master and slave. A minimum pause of 3.44ms must be adhered to by the master before it can send a request telegram. This is to allow the variable speed drive to definitively recognise that a request telegram is about to be received [19]. Before being able to send a response telegram back to the master the VSD must then observe at least a further 3.44ms before sending. Again, this is so that the master can recognise a response

telegram is about to start. If for some reason the master cancels a request telegram 2 start pauses must elapse before another telegram can be sent [19].

Address Byte

The address byte represents the address of the slave regardless of the type of telegram being sent. This allows the master to be able to specify to which VSD it wants to send a telegram and also to distinguish which VSD the response telegram was sent. The address range is between 0 and 255.Table 10 defines the address areas and corresponding definitions. More information is available in the SEW manual; “Serial Communication” available in Appendix C.

Address	Definition
0-99	Individual addressing with an RS-485 bus
100-199	Group addressing multicast (multicast) Special case of group address 100: “Means not assigned to any group”, i.e. ineffective
253	Local address: Only effective in conjunction with IPOS as master and the MOVILINK command. For communication within the unit.
254	Universal address for peer to peer communication
255	Broadcast address

Table 11 - Addressing Areas for RS-485 Communication [19]

Protocol Data Unit Type Byte

The protocol data unit type byte defines the type of communication and also contains information regarding the PDU. The type of communication can be cyclical or acyclical. As can be seen in Figure 18 the seventh bit determines this type. A value of 0 defines cyclical transmission and a value of 1 defines acyclical transmission. Cyclical transmission means that the master will transmit data to the VSD in a timed cycle. If no request is sent within a certain time, a timeout error will be recognised. Acyclical transmission is the sending of data by the master in no defined period. That is, the master does not have to send a telegram in a cyclical fashion.

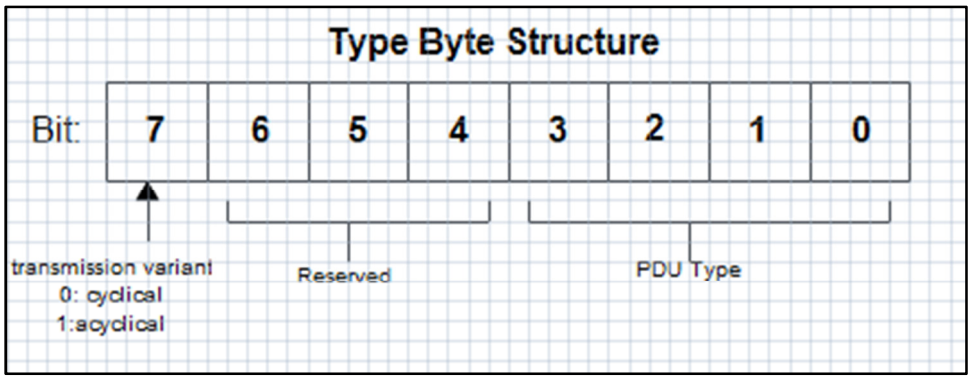

Figure 17 – Type Byte Structure

The following two tables (12 and 13) show the various PDU types for cyclical and acyclical data transmission. From these tables it can be seen that the length of a telegram can be calculated by:

Telegram Length = PDU Length + 4

Further information on these PDU types can be found in the SEW manual: Serial Communication, which can be found in Appendix C.

TYP Byte		PDU Name	Description	PDU Length in Bytes	Telegram Length in Bytes
00_{hex}	0_{dec}	PARAM + 1PD	8 bytes parameter channel + 1 process data word	10	14
01_{hex}	1_{dec}	1PD	1 process data word	2	6
02_{hex}	2_{dec}	PARAM + 2PD	8 bytes parameter channel + 2 process data words	12	16
03_{hex}	3_{dec}	2PD	2 process data words	4	8
04_{hex}	4_{dec}	PARAM + 3PD	8 bytes parameter channel + 3 process data words	14	18
05_{hex}	5_{dec}	3PD	3 process data words	6	10
06_{hex}	6_{dec}	PARAM + 0PD	8 bytes parameter channel without process data words	8	12

Table 12 - PDU Types in Cyclical Transmission [19]

TYP Byte		PDU Name	Description	PDU Length in Bytes	Telegram Length in Bytes
80_{hex}	128_{dec}	PARAM + 1PD	8 bytes parameter channel + 1 process data word	10	14
81_{hex}	129_{dec}	1PD	1 process data word	2	6
82_{hex}	130_{dec}	PARAM + 2PD	8 bytes parameter channel + 2 process data words	12	16
83_{hex}	131_{dec}	2PD	2 process data words	4	8
84_{hex}	132_{dec}	PARAM + 3PD	8 bytes parameter channel + 3 process data words	14	18
85_{hex}	133_{dec}	3PD	3 process data words	6	10
86_{hex}	134_{dec}	PARAM + 0PD	8 bytes parameter channel without process data words	8	12

Table 13 - PDU Types in Acyclical Transmission [19]

Block Check Character Byte

The final byte in the telegram is a block check character byte. This is to ensure that the VSD or master is receiving data of integrity. The block check character is calculated by an "exclusive or" logic operation using the parity of each of the transmitted bytes in a telegram. The process for this can be found in the SEW Manual: Serial Communication located in Appendix C.

4.2. Transmission Process

The transmission of the telegrams was discussed previously however this section will cover the method of transmission at the lowest level. This covers the serial transmission of each character in the telegram.

4.2.1. Character Structure

When using an RS-485 network with Movidrive MDX61B variable speed drives an asynchronous serial transmission process is used to transmit data. Each character consists of 11 bits and has the following structure:

- 1 start bit
- 8 data bits
- 1 parity bit
- 1 stop bit [19]

The first bit of the 11 bit character is a start bit. The actual data being sent is contained in the following 8 bits. The parity bit is next and is always an even number. This means that

each character is of even parity. The transmission of the data is completed when the stop bit is received. Figure 19 shows this structure.

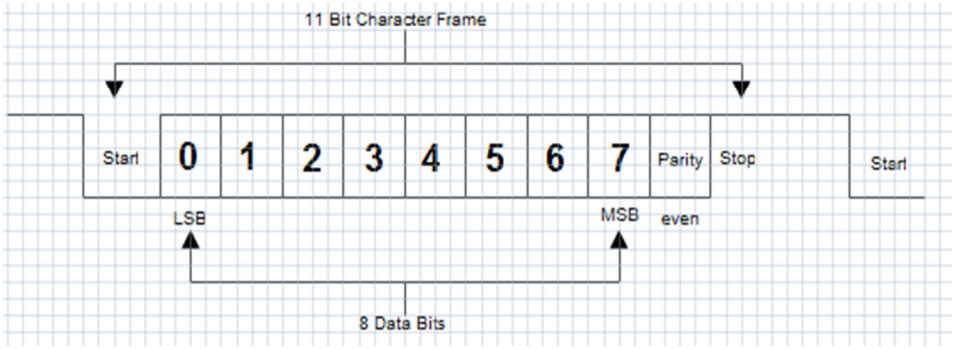

Figure 18 - Character Structure

CHAPTER 5: Bench Top Testing Platform

This chapter will discuss the implementation of the hardware to form the bench top testing platform. Although previous work had been completed on this project, there were some issues with the existing bench top testing system which needed to be addressed. Insufficient documentation was available for the project to be resumed from the previous position so a complete overhaul was necessary.

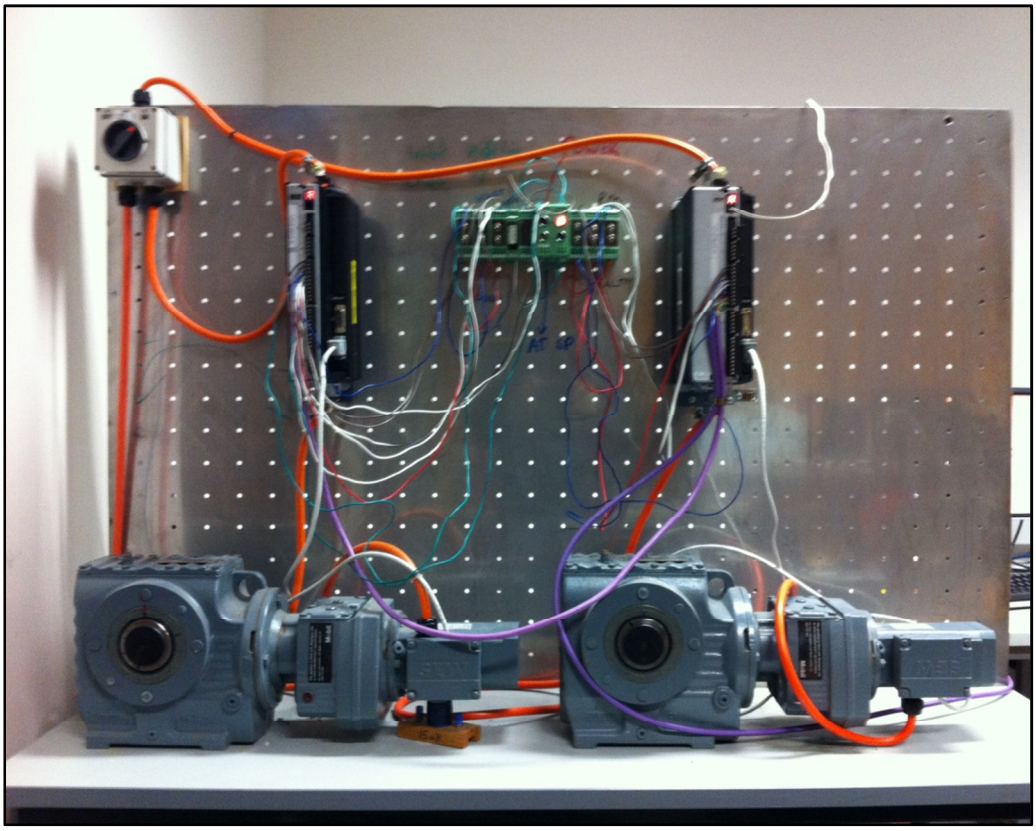

Figure 19 - Bench Top Testing Platform Once Reconnected and Operational

5.1 Connections and Wiring

Previous work on the solar tracker neglected a significant amount of documentation, particularly in wiring and connection of the variable speed drives. A large emphasis was placed on research and documentation for future students, to aid any future progress on this project. By carefully documenting all changes and progress, it is hoped that the issue of inadequate documentation will not reoccur.

5.1.1 VSD Connection

The Movidrive MDX61B units had previously been mounted and connected to a three phase power source by John Boulton. John had also connected the three-phase power to the synchronous servo motors. An array of testing switches had been mounted to the

testing platform however these were no longer correctly wired in to the input terminal. The RS-485 interface was also re-connected.

RS-485 Connection

The connection terminals for the RS-485 interface are located at terminal X13:10/11. Terminal X13 is a set of isolated binary inputs that are used in the operation of the VSD. The specifications for the cable required are as follows:

- 4-core twisted and shielded copper cable
- Cross section of 0.25 to 0.75mm^2
- Cable resistance between 100-150Ω at 1MHz

The Profibus A type cable fit these criteria and was used for the connection of the RS-485 interface. The positive wire of the cable was connected to input X13:10 and the negative wire to X13:11. The VSD's also required that the shielding of the cable be connected to the digital ground input at X13:9. Figure 21 shows this wiring diagram and also how multiple VSD's should be connected together on the RS-485 network. No external termination resistors are needed on the bus as the VSD's are already equipped with internal terminating resistors [16].

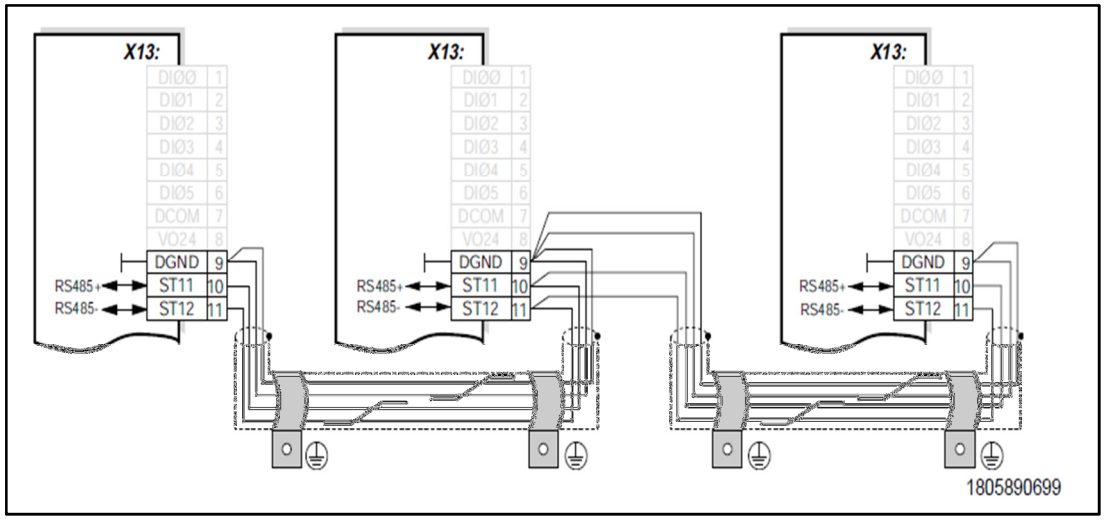

Figure 20 - Wiring Diagram of the RS-485 Interface [16]

The RS-485 cable then needs to be interfaced to the master computer. A terminal block was used to connect the positive, negative and ground wires to a 9 pin D-sub connecter (Fig 22). Only 3 of the pins are needed to be connected (pins 1, 4 and 5). These are the RxD-, RxD+ and the common ground pins. A full list can be seen in table 13. A 120Ω terminating

resistor needs to be connected, on the computer side, across the bus lines. Without this resistor signals can be reflected back to the bus and this can lead to the corruption of data.

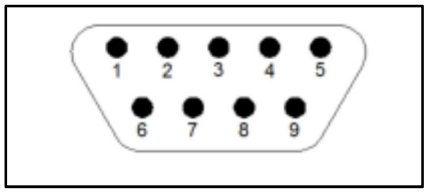

Figure 21 - 9 Pin D-sub Connector

Pin Number	Signal Name	Description
1	GND	Common Ground
2	CTS+	Clear to Send +
3	RTS+	Ready to Send +
4	RXD+	Received Data +
5	RXD-	Received Data -
6	CTS-	Clear to Send -
7	RTS-	Ready to Send -
8	TXD-	Transmitted Data +
9	TXD+	Transmitted Data -

Table 14 - 9-pin D-sub Pin Assignment

Terminal X13

Terminal X13 is a set of isolated binary inputs that are used for the operation of the variable speed drives. An input list for terminal X13 with an enabled bus positioning IPOS program can be seen in Table 14:

X13 Pin Number	Type	Name
1	DI00	Controller Inhibit
2	DI01	Enable
3	DI02	Fault Reset
4	DI03	Reference CAM
5	DI04	CW Limit Switch
6	DI05	CWW Limit Switch
7	DCOM	DCOM
8	VO24	VO24
9	DGND	DGND
10	RS-485 +	RS-485 +
11	RS-485 -	RS-485 -

Table 15 - X13 Terminal Input List [16]

These digital inputs are involved with the start-up and operation of the connected servo motor. Digital inputs 0 to 5 are wired into temporary switches. When implemented in the final system research will have to be undertaken to decide and purchase the correct switches for the field. Terminal X13 has one output that provides a 24V dc signal, this being X13:8. This signal is utilised to power the temporary switches in the bench top testing platform. When using this 24V signal to power binary inputs a jumper is connected between X13:7 and X13:9. As previously discussed inputs X13:10/11 are connected to the RS-485 cable.

5.2. VSD Initialisation

Once the connections and wiring of the drive had been established the drives were initialised. This required direct communication to the drives using the Movidrives proprietary software Movitools. Direct communication to the drive was achieved through the XT port of the VSD. The XT port is a separate RS-485 interface that can be utilised by a keypad or in this case for the connection to the Movitools software [16]. This can be done by using either the SEW RS-485 to RS-232 converter or the RS-485 to USB converter (See Fig 23 and 24).

Figure 22- SEW RS-485 to RS-232 Converter

Figure 23 - SEW RS-485 to USB Converter

5.2.1 Movitools Drive Connection

Movitools is the proprietary software provided by SEW to establish a connection and initialise all the drive parameters. In a new project the VSD's were added on to a network and a choice of IPOS program and its parameters were selected and downloaded to the drive. Movitools initially scanned the RS-485 interface until it detected a connected variable speed drive. The process was needed to be repeated as only one drive can be connected at a time, unless multiple SEW converters are available. Following this, the drives were added on to the same network where each individual VSD was assigned an address. These addresses are used in determining where a telegram is to be sent or

received in the network. A user guide for initialising an SEW variable speed drive has been created and can be found in Appendix D.

5.2.3 IPOS Program

As has previously been mentioned the Movidrive MDX61B VSD's come equipped with an integrated positioning and control system known as IPOS Plus. It is this program that handles the positioning and control of the connected motor. A decision had been previously made to utilise the existing IPOS module known as "Positioning via Bus". This IPOS module is suitable for applications that utilise a direct drive motor mounting position. The module is selected in Movitools and provides a setup interface that just requires parameters regarding the motors and drives to be entered. An example of this can be seen in Figure 25. In this process a referencing travel type was selected.

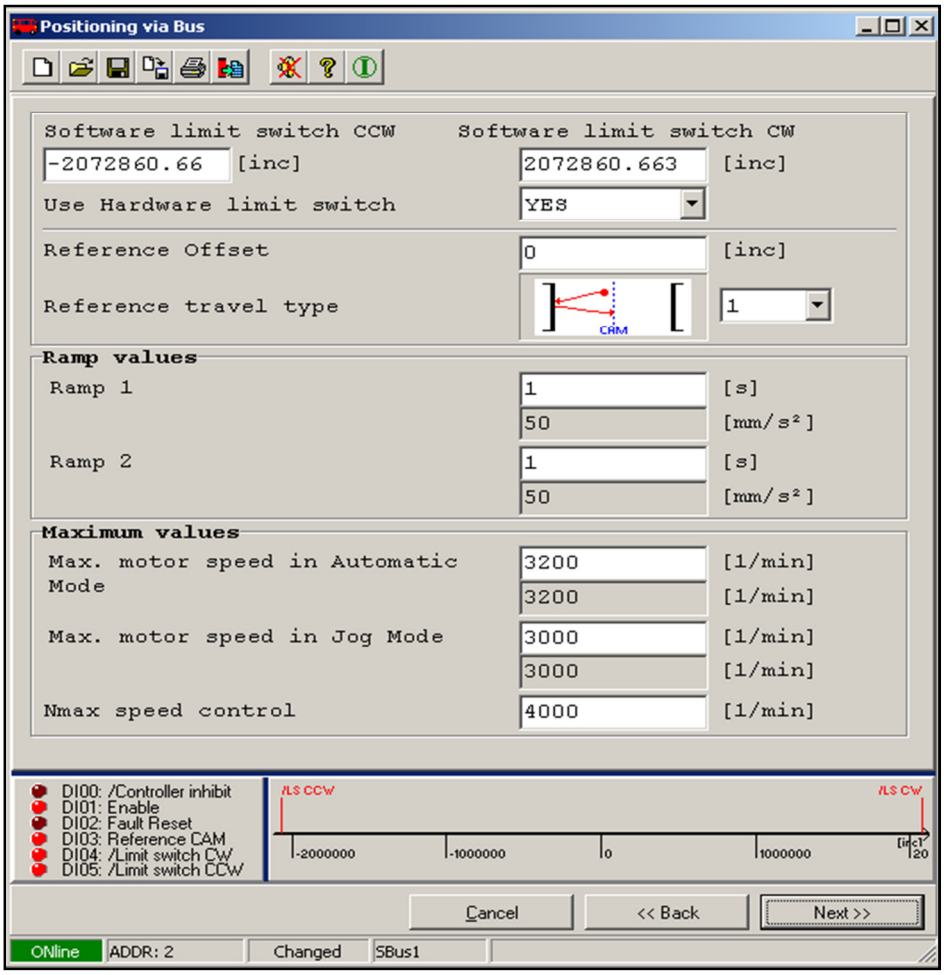

Figure 24 - Example Positioning via Bus Interface

5.2.4 VSD Referencing Mode

There are 9 different modes of referencing available for use within the IPOS program. A decision needed to be made on which referencing mode was most appropriate for the solar tracker. The reference modes are:

- **Type 0: Reference travel to zero pulse**
    - In this reference mode the reference position is at the first zero pulse detected when the reference travel is counter clockwise [18].
- **Type 1: Counter clockwise end of the reference cam**
    - The motor is referenced when a reference cam signal is seen by the VSD. The direction of travel is counter clockwise and the signal must be a pulse, meaning a rising and then falling edge must be seen before the motor references.
- **Type 2: Clockwise end of the reference cam**
    - The reference point of the motor is determined by a reference cam signal. The signal must be a pulse and the direction of travel for referencing is clockwise rotation.
- **Type 3: Clockwise limit switch**
    - The motor will reference upon contacting the limit switch. The reference travel direction is clockwise.
- **Type 4: Counter clockwise limit switch**
    - The motor will reference upon contacting the limit switch. The reference travel direction is counter clockwise.
- **Type 5: No reference travel**
    - The motor takes its machine zero from wherever it currently is.
- **Type 6: Reference cam flush with the clockwise limit switch**
    - The reference point is the first zero pulse or falling edge to the left of the reference cam [18].
- **Type 7: Reference cam flush with the counter clockwise limit switch**
    - The reference point is the first zero pulse or falling edge to the right of the reference cam [18].
- **Type 8: Without enable**
    - Referencing can take place when the drive is not enabled. The reference point is the motors current position [18].

Further information can be found in the SEW manual; IPOS Positioning and Sequencing Control. This can be found in Appendix C.

Discussion

For the solar tracking system it was decided that reference type 1, referencing to the counter clockwise end of the reference cam, be used. Since a signal is used to determine the reference point and it requires a rising and falling edge, a magnetic reed switch would be appropriate for the motor to reference machine zero. The benefit of this is that the motor can reference to a true zero which requires no offset for the motor. Referencing to the limit switches would also be appropriate however it would require an offset to be determined for machine zero. Further research would then be required to determine the most appropriate referencing method out of types 1, 2, 3 and 4.

5.3. Control Structure

The control structure of the overall system can be seen in Figure 26. It displays the hierarchical structure of the overall system. A computer running the Labview program will control the requests made to each of the VSD drives via the RS-485 communication interface. The computer will need to have a National Instruments RS-485 card installed to be able to communicate via Labview over RS-485 to the variable speed drives. The computer will be mounted on site near the final constructed system. A decision will need to be made on the computer as factors such as heat and dust could affect the operating capabilities of the computer.

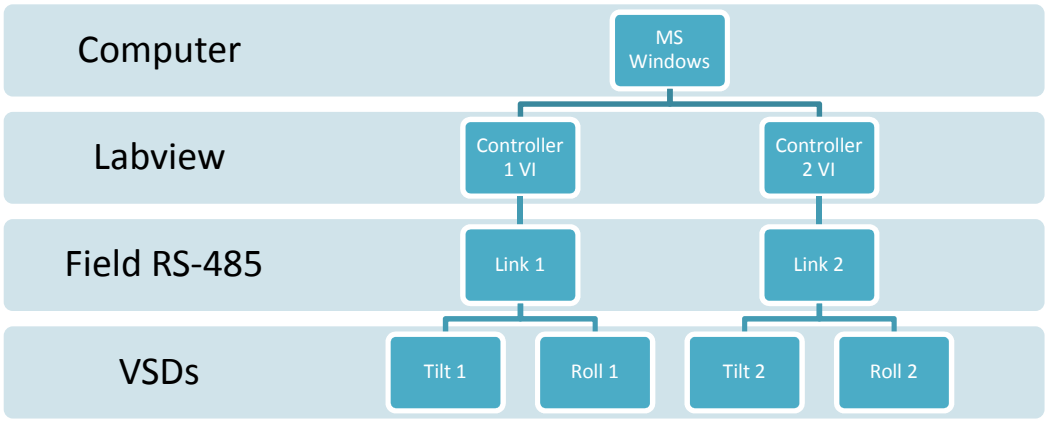

Figure 25 - Control Structure of the Solar Tracking System

CHAPTER 6: Tracking Program Development

An existing tracking program developed by Rhyss Edwards was previously used as the controller for the solar tracking system. This Labview program has been further modified to improve the transmission of data from the Labview program to the variable speed drives. An overview of the program and the changes made to it will be discussed in this Chapter.

6.1 Controller Overview

There are 3 main modes of the Labview controller. They are the reference mode, automatic mode and jog mode. Each of these modes can be selected via a tab on the front panel of the Labview program. Upon start-up of the program the controller automatically enters the reference mode. Once referenced the operator has the choice of whether to control the system automatically or manually via the jog mode. Figure 27 shows the front panel of the Labview Program.

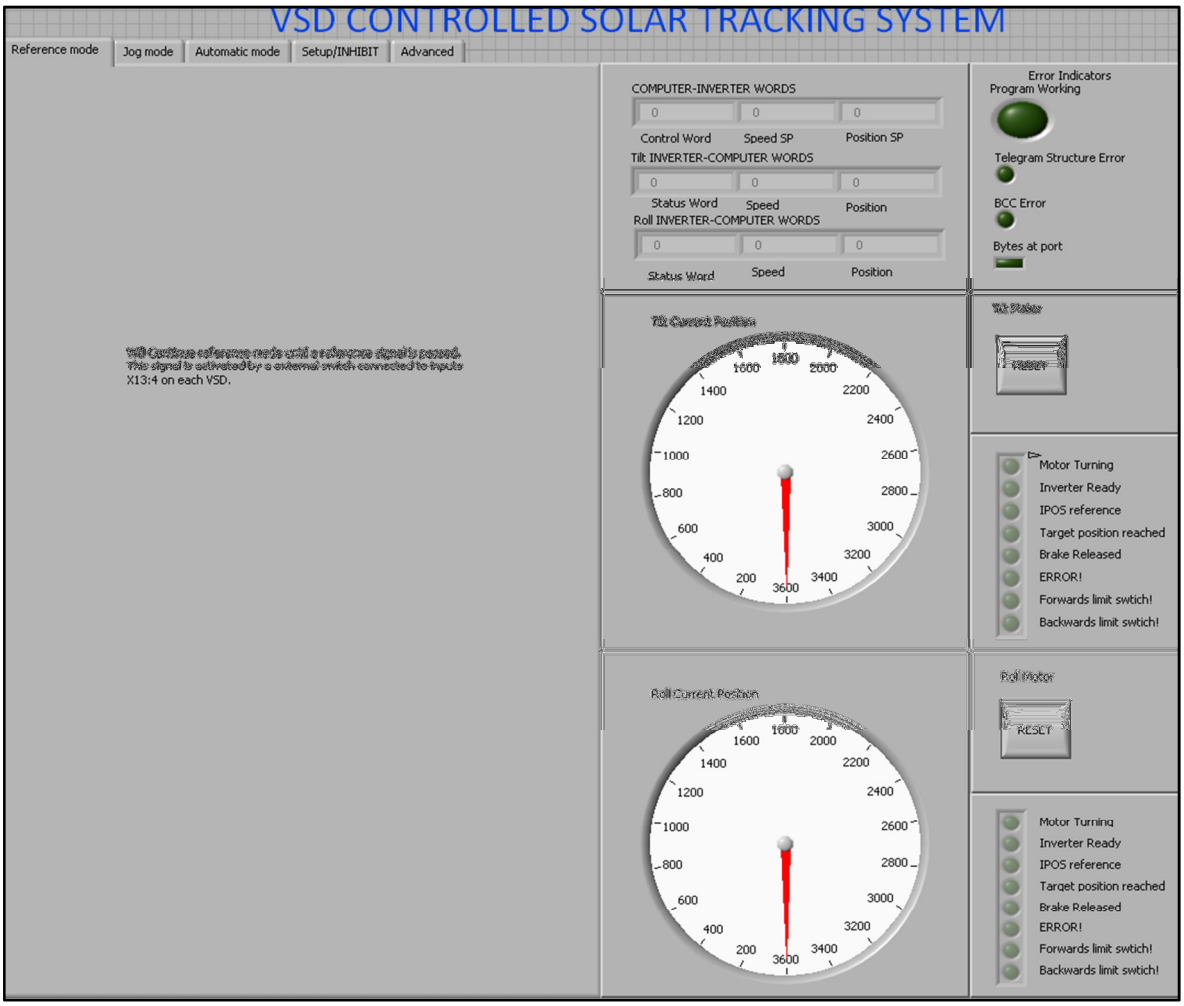

Figure 26 - Labview Front Panel

6.1.1. Reference Mode

In the reference mode the program sends a request to the VSD to move the motors in a counter clockwise direction at a designated reference speed. The program then waits until a reference signal has been passed through the inverter which stops the motor and designates the position as machine zero. This signal is activated via a switch wired in to terminal X13:4 on the VSD's. Once referenced the IPOS reference indicator will be activated on the front panel (see Fig 28).

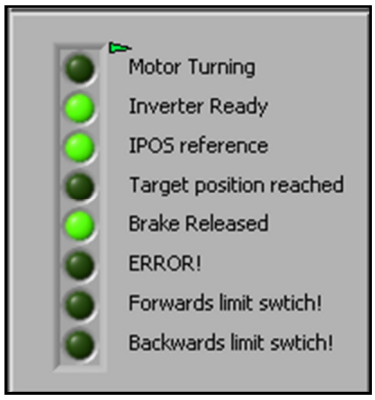

Figure 27 - Motor Indicators

6.1.2. Automatic Mode

The automatic mode can be accessed via the tab on the front panel. Within this mode (see Fig 29) there is the option of having the tracking system be in tracking mode, manual stow mode and cleaning mode. The manual stow position moves the array into the stow position if the operator needs to stow the array during the day. The cleaning mode moves the array into a position conducive to cleaning. The tracking mode is used for tracking of the sun.

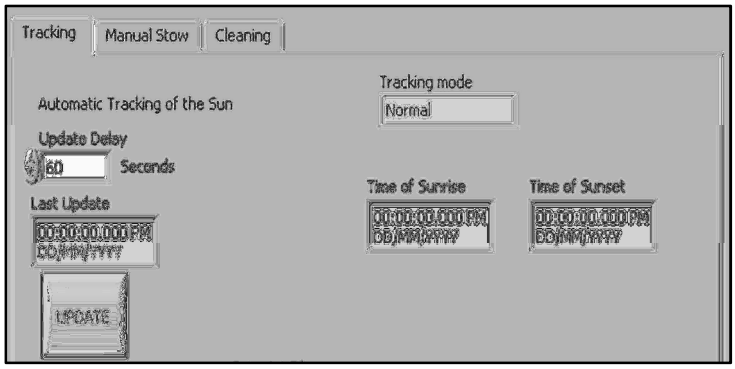

Figure 28 - Tab Options in Automatic Mode

Tracking Mode

The tracking mode front panel (see Fig 30) gives the operator the ability to change the speed of the motors, the update delay, and the tilt and roll offset values. Figure 30 shows

the front panel of the tracking mode. The program updates the set point information depending on the value in the update delay. Within the tracking mode there are 5 possible states that the program can enter depending on various conditions. These states are as follows:

- **Normal –** When in the normal state all set point values are held until the next update.
- **Update –** Updates the set point for both motors based on the solar tracking algorithm.
- **Software Limits –** Motors are moved into the stow position when the software limits are reached by the motor. Waits until the set points for each motor are back within the limits.
- **Night Stow –** When the sunset time is reached the array moves in to the stow position until the following days sunrise.
- **Wind Stow –** Moves the array into the stow position and waits until the wind speed is below that of the allowed limit.

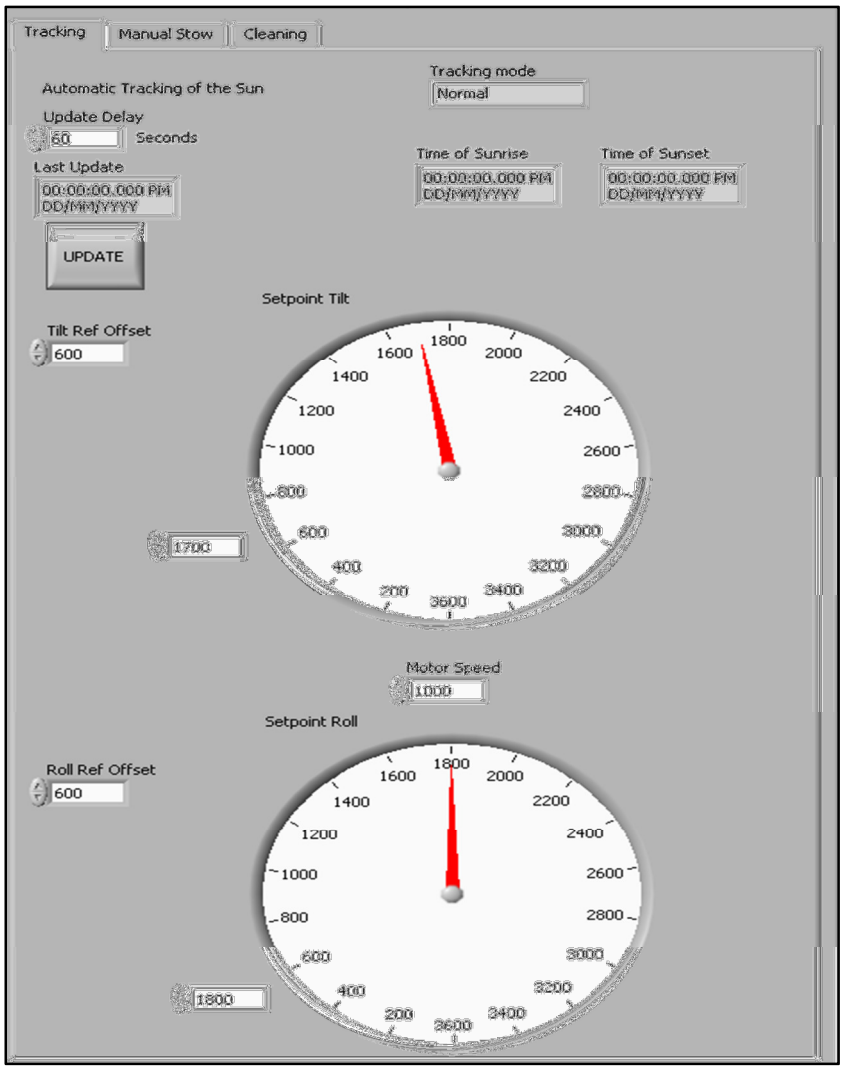

Figure 29 - Tracking Mode Front Panel Features

6.1.3. Jog Mode

This mode allows the operator to manually jog the motors backwards and forwards as a method of manual control. A bug has been identified that does not allow the motors to reverse once the motors have been referenced and automatic mode has been operating. Instead the motors only move forwards. An investigation into this issue was undertaken.

Jog Backwards Error

An investigation was carried out to try and determine the cause of the issue. The program disabled one of the VSD's so that only one was being controlled. The request telegrams were then monitored to determine which byte was sending the wrong information. Once the motor was referenced the motor was jogged backwards and the telegrams were monitored and documented. The tracker was then put into automatic mode and then back

into jog mode. The motor was jogged backwards, which due to the error moved the motor forwards, and the request telegram monitored. The hypothesis was that the telegram where the bug was present would have a byte that differed, from when the motor jogged backwards correctly. This was thought to be the cause of the problem. This however proved to be untrue as the telegrams always remained the same. No fix was able to be found. However, it appears that the issue may be occurring within the IPOS program rather than the programming in Labview. The telegrams for each are as follows:

Telegram When Motor Jogs Backwards	Telegram When Error is Present
02 01 05 0D 06 03 E8 04 3C DE	02 01 05 0D 06 03 E8 04 3C DE

Table 16 - Monitored Telegrams

6.2. Program Development

A major focus was on improving the data transfer between the Labview program and the VSD. This was due to the previous method lacking adequate sequencing and structuring of the data transfer process. This involved developing a more sequenced and structured method of transmitting the data from the controller to the roll and tilt VSD's. The previous method used was structured incorrectly. Instead of sending a telegram to ask for information from the drive first, the program would first read whatever bytes were at the drive. The new method first sends a request telegram to the VSD and then waits for a response. This structure is more appropriate for RS-485 transmission. The RS-485 read and write operations are now integrated in a state structure. There are 5 states that control the read and write processes these are:

- Initialisation
- Send Request
- Get Response
- Process Message
- Do Nothing

6.2.1 Read and Write Process

The 5 states have been designed in order to provide a specific sequence for the telegrams to be sent and received. This will lower the chance of telegrams with corrupt data being transmitted. The program will not enter the next state unless all conditions in the previous

state have been met. This ensures that the correct telegram is being delivered to the correct VSD.

Initialisation

This state (see Fig 31) initialises the values in the shift registers so previous values aren't fed into the program. Once initialised, the program moves into the "Send Request" state.

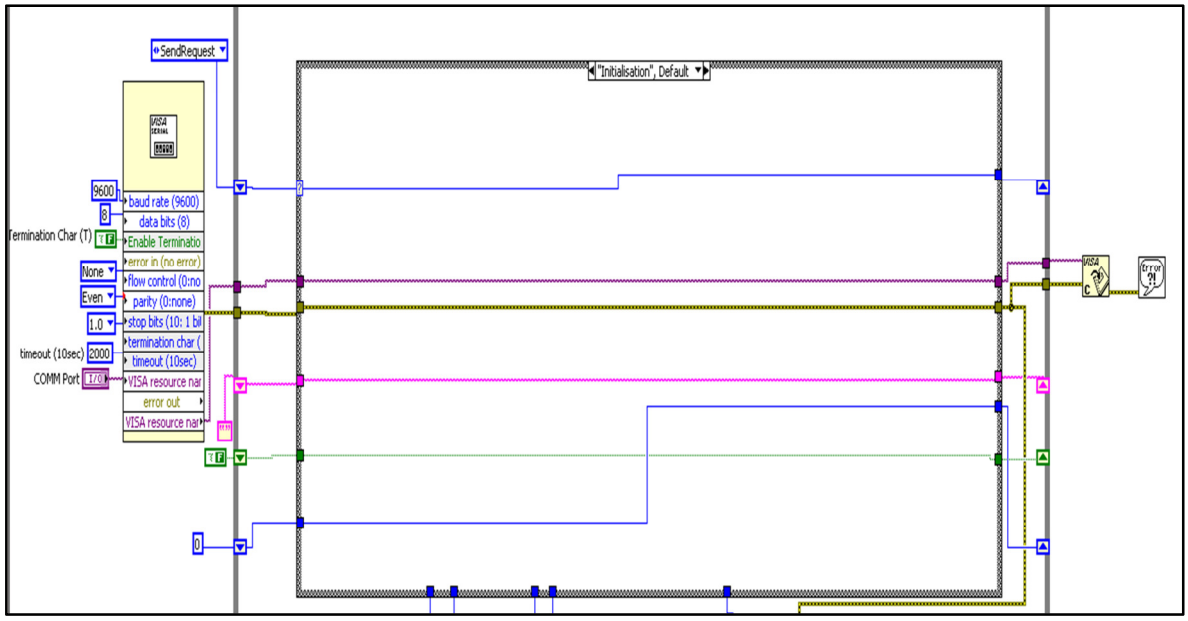

Figure 30 - Initialisation State

Send Request

Once initialisation has taken place the program enters the "Send Request" state. A request telegram is generated from the information in the tracking section. The generate output subVI then compiles the information and sends the request as a string to the VISA write module. This module opens the port and transmits the telegram over the RS-485 network to the variable speed drive. Once complete, the program moves into the "Get Response" state.

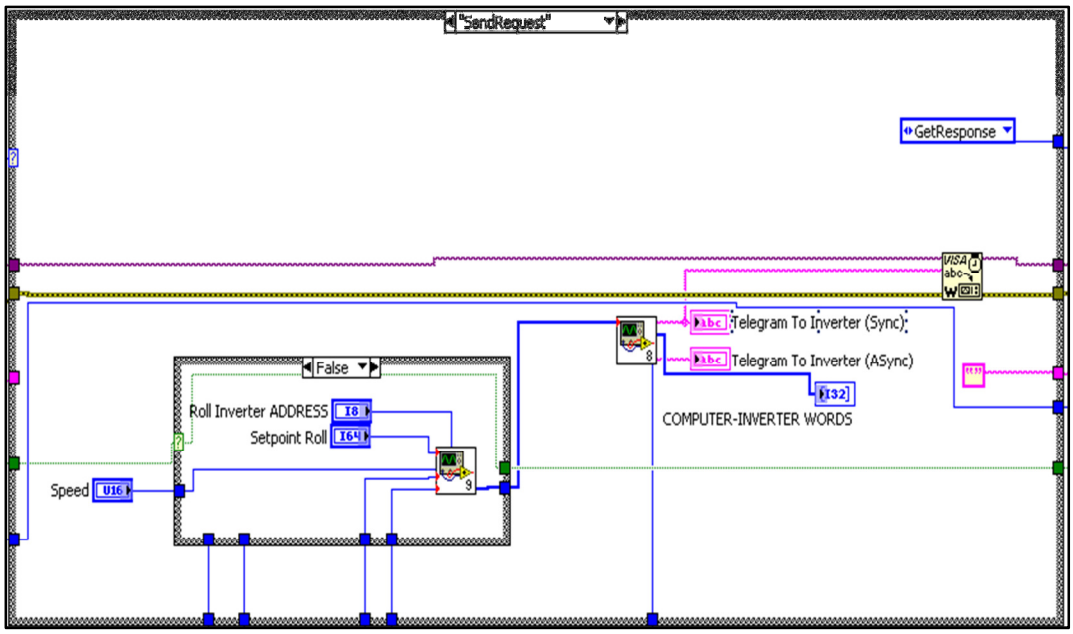

Figure 31 - Send Request State

Get Response

In this state the program initialises the VISA read block to accept 10 bytes from the port. A light on the front panel will be displayed on the front panel to signify that there are bytes at the port. This is useful in the debugging process as it can determine whether information is being received. The bytes are then converted from an integer to a string. From here the program confirms that 10 bytes have been received before it can move in to the next state. The converted string is then displayed in the advanced tab on the front panel for error checking purposes.

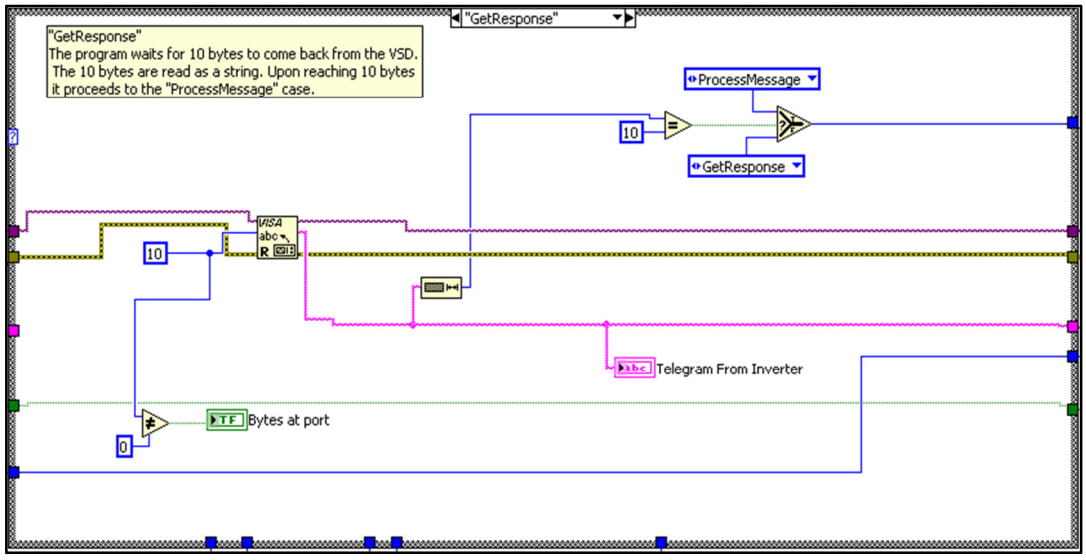
"GetResponse"
"GetResponse"
The program waits for 10 bytes to come back from the VSD.
The 10 bytes are read as a string. Upon reaching 10 bytes
it proceeds to the "ProcessMessage" case.
ProcessMessage
GetResponse
Telegram From Inverter
Bytes at port

Figure 32 - Get Response State

Process Message

This state processes the response telegram from the VSD to retrieve the motor position and the operating status information of the motor so it can be displayed to the operator on the front panel. The telegram must first be processed in the Check Telegram subVI. This determines whether the telegram adheres to the correct structure that was explained in Chapter 4. Within this subVI a Block Check Character (BCC) check is also computed to determine the telegrams validity. If the telegram fails either the telegram structure or BCC check then the program will return to the "Send Request" state in order to repeat the process and receive a valid telegram.

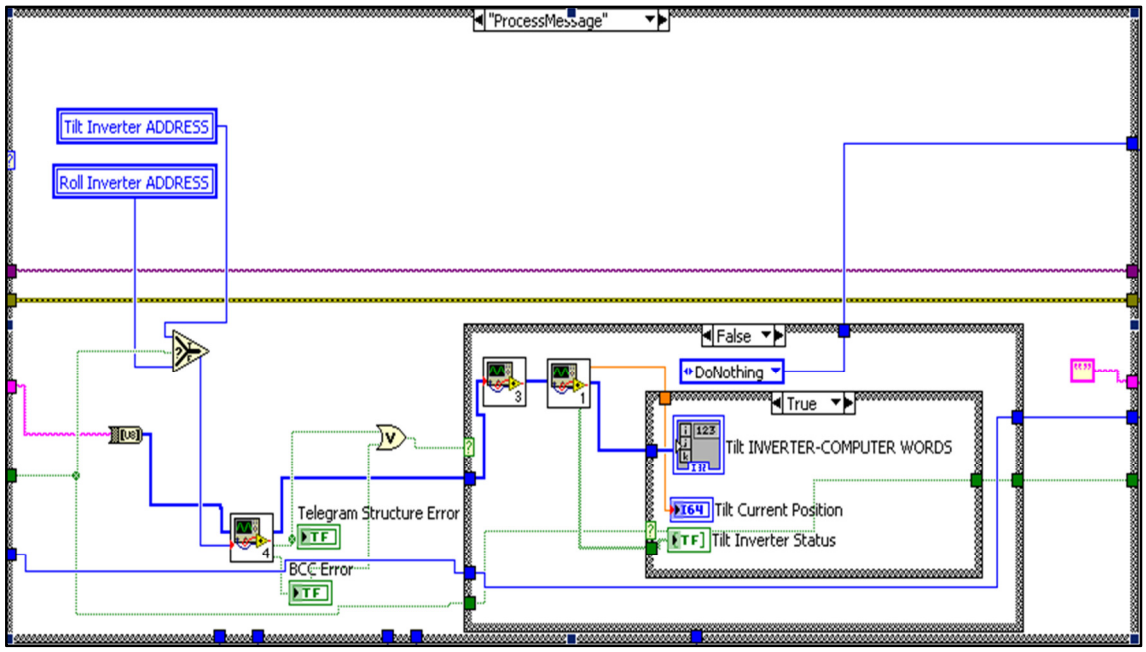

Figure 33 - Process Message State

Do Nothing

Despite the name of this state being called "Do Nothing" it does actually have a purpose. The program will only enter this state once the successful sending and receiving of a telegram has occurred. It signifies the end of the sending and receiving process and enables the program to move back into the "Send Request" state to send further data. It is also the state where the program decides which VSD is to be the sender and receiver for the following loop. Since the loop time is 100ms the program sends and receives telegrams to both VSD's every 200ms.

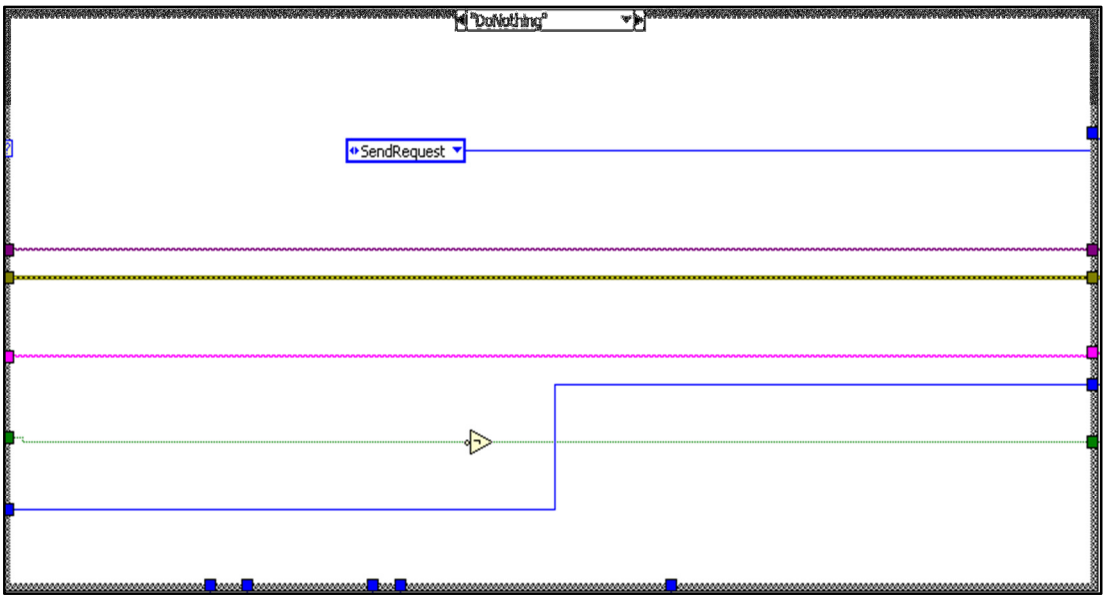

Figure 34 - Do Nothing State

6.2.2 Discussion

The new method of sending and receiving data has streamlined the process and given the program a more suitable structure for this process. Whilst the program is fully functional a temporary fix has been included for one minor issue. When a response telegram is being processed it must pass the telegram structure and BCC check. Failing this the program would be sent back to the “Send Request” state. This in theory works fine. However, due to the program not being able to switch the VSD it becomes out of sync with the telegram and the error becomes permanent. The temporary fix was to implement a count function that counts the amount of times the errors occur and when it reaches 10 the program will enter the “Do Nothing” state where the VSD is switched (See Fig 36). This currently fixes the telegram error and resynchronises the program. A fix for this was unable to be completed. However, finding a different position for when the program switches communication between VSD’s could be one solution. A count method should remain in the error case and a message displayed if the error occurs 10 times in a row.

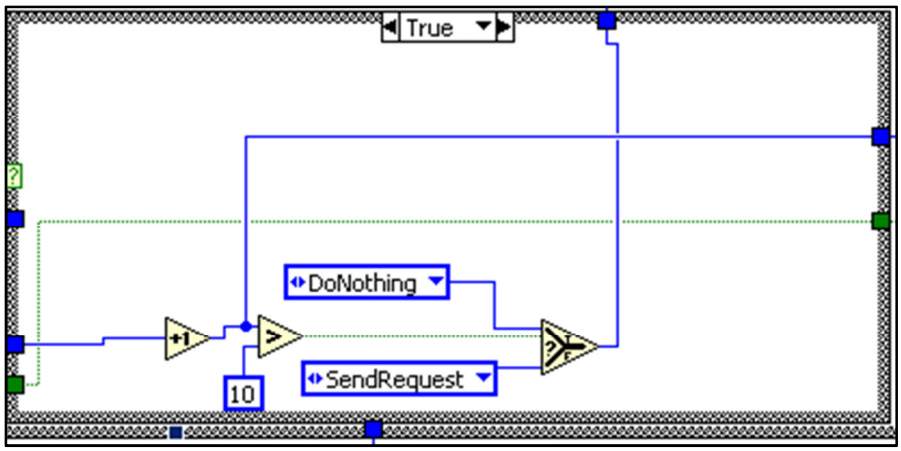

Figure 35 - Temporary Error Correction

The new modified send and receive process has now also improved the way in which the master communicates to multiple drives. The previous method used the loop counter to determine which drive a telegram was to be sent to and received by. Every loop it would alternate between the two drives. The issue with this method was that it was possible for only part of a telegram to be received in one loop and then the program would switch VSD's to communicate with. This method can be seen in Figure 37. The new process waits until the whole message has been received from the VSD before it will switch communication to the drives. This lowers the chance of corrupt data being transmitted over the RS-485 network.

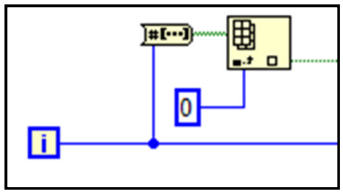

Figure 36 - Previous Method for Controlling Multiple VSD's

CHAPTER 7: Conclusion

7.1. Project Conclusion

The use of variable speed drives and its associated technologies has become increasingly popular in industrial applications. This can be attributed to the many advantages they offer to motor driven systems. These advantages include; the ability to operate a motor in a wide range of speeds and the ability to increase energy efficiency in motor driven applications [2]. This technology has been implemented in the design of a solar tracking system for use at Murdoch University.

Work on the development of the solar tracking system had previously been completed by the students of ENG454 in 2009 and further developments were made by Rhyss Edwards in his thesis "Control System Design and Commissioning of Photovoltaic Trough Concentrator Systems Installed at the Murdoch University South Street Campus" in 2010 [1]. This work had left the project with a functional, albeit not totally robust, Labview controller. Thus, further development was needed.

The project focussed on three key stages; research and documentation, robust testing and further development on the tracking program. From very early on it was apparent that the existing system lacked suitable documentation in regards to the system set up and key operational instructions. The majority of the early stages of the project were focussed on the research of the existing tracking system and its key components. These components included; variable speed drives, servo motors and RS-485 communication technologies. A review of the specific SEW Movidrive MDX61B was undertaken to ensure that correct connections and wiring procedures could be completed to advance to the next stage of the thesis. Key documents were gathered on the information researched and documentation has been produced for the initialisation of the variable speed drives and correct operational procedures. These documents have been included in the Appendices. Once enough knowledge had been gained the robust testing of the bench top testing platform was commenced.

The primary task of the robust testing phase was to replicate the position that Rhyss Edwards had achieved in his work on the project in 2010. This process was complicated by the lack of documentation. Establishing direct communication of the variable speed drives was achieved using the proprietary software SEW Movitools and allowed an IPOS control program to be configured and downloaded on to the drives. First control of the motors was

achieved here using this software. Following this, the existing Labview controller was used to establish communication, manual and automatic control of the tilt and roll motors. Several programming issues such as the method of data transmission and multiple motor control arose throughout this stage which led to the improvements and further developments to the solar tacker program in the final stage.

Improvements were made to the existing Labview tracking program throughout the development stage. In the testing phase it had become apparent that there were issues regarding the transfer of data to the variable speed drive on the RS-485 network. To address these issues the RS-485 read and write operations were re-developed within the Labview program. A more sequenced and structured read and write stage was implemented resulting in a more accurate method of data transmission. Greater error checking methods were also employed in the read and write process to ensure that only reliable data was being passed to and from the VSD. Minor changes were made to the front panel of the program to make it more user friendly for future students.

A greater knowledge of variable speed drives, Rs-485 communication and more specifically the transmission data across this interface has been attained and recorded throughout this project. This will aid staff and students if these technologies are used in other projects or applications in the engineering course. The solar tracking program is fully operational albeit for some minor bugs, but these are far less than when the project was started. The goals that were set out to be attained throughout this project have been achieved. The project has a large scope for improvements and future work, which can be undertaken to further develop the solar tracking system.

7.2. Future Work

There is potential for advancements to be made to the solar tracking system due to the complex nature of the system. Future works that should be undertaken on this project are as follows:

Labview Tracking Program

The provided Labview program provided is currently fully functional. However further improvements should be made to the program. These include:

- Finding a solution to the reference mode reverse problem. This problem was first documented by Rhyss Edwards in 2010. Testing was undertaken in this project to try and discover the issue. Telegrams being sent to the VSD's were monitored and no difference in the telegrams was noticed in reference mode compared to non-referenced. More information can be found in Chapter 6.
- Telegram Structure Error and BCC check error. Currently when these errors occur, albeit rarely, the state of the transmission process becomes out of sync with the VSD. A temporary solution has been employed however; it currently does not address the errors appropriately. This method is unsuitable for final implementation so a solution is required. Further details are available in Chapter 6.
- Implementing hardware limit switches. Previously hardware limit switches were not enabled within the VSD's. This has been corrected and test limit switches are now functional. An error reset method needs to be employed in Labview so the error can be cleared from the VSD via the front panel of the controller.

Referencing Method

Currently the reference method existing on the variable speed drives is "counter clockwise end of the reference cam". There are 8 other methods of referencing available in the IPOS control program. Referencing via limit switches has been tested and successfully used in these tests. Further research will have to be done to decide which reference method best suits the solar tracker for use in the final tracking program.

Anemometer

Procurement of an anemometer is advised for use on the final constructed system. Wind damage could be possible if the final system has no way of stowing if dangerous winds were to come. So an anemometer is required to detect wind speed. It has been decided that the condition for determining when the tracking system shall be stowed will be when a wind gust of 70km/h is detected for 2 seconds [1]. This was documented by Rhyss Edwards in the previous work and is currently the method used on the large array tracking system at Murdoch University [1].

The options for implementing the anemometer in the Labview program will have to be further explored. There is a terminal for analog inputs and also a terminal of digital inputs

on the Movidrive MDX61B VSD. The analog inputs are available for determining a set point for the motors. Since this set point method is not employed by the current tracking program, further research will be needed in order to determine whether the analog input can be utilised for other devices. Failing this method the currently unused digital inputs on terminal X13 can possibly be used. Once again further research will be required to explore this option. If this is possible, staff and a technical officer will need to be involved so that a design for the anemometer can be decided. The anemometer will need to output a digital signal when the wind speed is above the current limit threshold.

Field Implementation

A motor mount design was decided upon by Rhyss Edwards in consultation with Murdoch staff in 2010. John Boulton was heavily involved in this process and consultation with him will be necessary to mount the roll motors. Following this a renewable energy medium will need to be decided upon. Ideas were put forward by Rhyss Edwards these included solar panels, solar troughs or solar thermal systems [1]. After consultation with Graeme Cole a decision has yet to be made. He indicated the possibility to use a variety of renewable energy mediums on the one array to increase the value as a teaching tool. The decision will need to include engineering staff as the final system will be a teaching tool for use in the Industrial Computer Systems and Renewable Engineering streams.

Further to that limit switches will need to be chosen and procured for use as the CW and CCW limits. If the reference cam reference method is chosen a switch for this reference point will also be decided. It is possible that this could be a magnetic reed switch so the motor can pass it once to reference (a rising and falling edge is needed). Since the limit switches are used by the VSD's the option of low voltage limit switches is possible [1].

Further components and plans need to be decided upon as noted by Rhyss Edwards in 2010. These are:

- Field cabinet selection
- Sourcing a Field PC
- Wiring Diagrams
- Field box design [1]

These items will need to be sourced and designed so the final solar tracking system can be implemented at the Murdoch University campus.

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Appendices

Please see the CD for the following appendices.

Appendix
A – Solar Tracking Program
• Labview Controller
• Previous Version
B – Labview Programs
• Control of One VSD
• Movidrive Read and Write
C – SEW Manuals
• Movidrive MDX61B
• Servo Motors
D – Documentation
• Installing an IPOS program
• Labview Solar Tracker User Manual
• Input/Output List
E – SPA
• Solar Tracking Algorithm Manual
F – Progress Report and Proposal